Plastic Pollution, People, and Policy

The threefold potential of citizen science for scientific knowledge generation, behavior change, and policy influence

Oturai, Nikoline Garner

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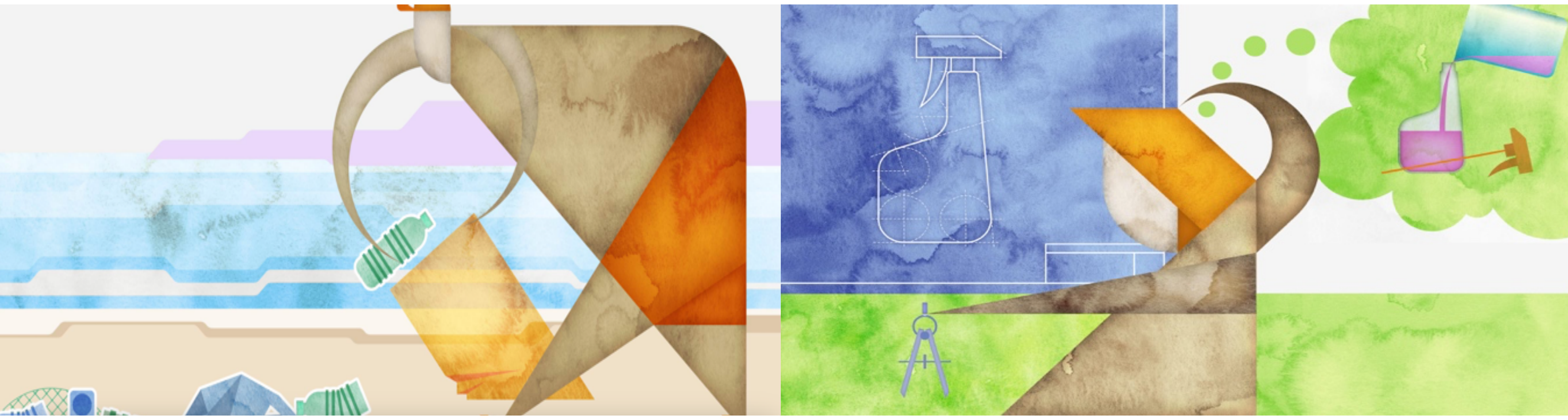

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The threefold potential of citizen science for scientific knowledge generation, behavior change, and policy influence

This thesis has been submitted to the Ph.D. School of Science and Environment by
Nikoline Garner Oturai with supervisor Kristian Syberg
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UNEP *Beat Plastic Pollution*, Visual Feature,
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"Only within the moment of time represented by the present century has one species – man – acquired significant power to alter the nature of the world."
(Rachel Carson, Silent Spring, 1962)

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Acronyms

CEI	Citizen engagement initiative
EC	European Commission
ECI	European Citizens' Initiative
ECSA	European Citizen Science Assoc.
EU	The European Union
JRC	Joint Research Centre
MSFD	Marine Strategy Framework Directive
PEB	Pro-Environmental Behavior
SDG	Sustainable Development Goals
SUP	Single-Use Plastic
UN	The United Nations
UNEA	United Nations Environmental Assembly
UNEP	United Nations Environmental Programme

List of scientific contributions

Scientific contributions included in the thesis

My PhD thesis is based on four published papers (I – IV), and one (V) manuscript accepted with minor revisions. Papers are listed in order of history and flow. I am responsible and first author of papers (II), (III), and (V). Papers (I) and (IV) are based on group collaboration, with my substantial impact. My initials are NBO (Nikoline Bang Oturai) and after marriage NGO (Nikoline Garner Oturai).

(I) Syberg, K., Palmkvist, A. M., Khan, F. R., Strand, J., Vollertsen, J., Clausen, L. P. W., Feld, L., Hartmann, N. B., **Oturai, N. B**., Møller, S., Nielsen, T. G., Shashoua, Y. & Hansen, S. F. A nationwide assessment of plastic pollution in the Danish realm using citizen science. (2020) *Nature Scientific Reports*, 10 (1) https://doi.org/10.1038/s41598-020-74768-5

(II) **Oturai, N. G**., Pahl, S. & Syberg, K. How can we test plastic pollution perceptions and behavior? A feasibility study with Danish children participating in "the Mass Experiment". (2022) *Science of the Total Environment*, 806 (4) https://doi.org/10.1016/j.scitotenv.2021.150914

(III) **Oturai, N. G.**, Nielsen, M. B., Clausen, L. P. W., Hansen, S. F., & Syberg, K. Strength in numbers: How citizen science can upscale assessment of human exposure to plastic pollution. (2021) *Current Opinion in Toxicology*, 27 https://doi.org/10.1016/j.cotox.2021.08.003

(IV) Clausen, L. P. W., Hansen, O. F. H., **Oturai, N. B**., Syberg, K. & Hansen, S. F. Stakeholder analysis with regard to a recent European restriction proposal on microplastic. (2020) *PloS One*, 15 (6) https://doi.org/10.1371/journal.pone.0235062

(V) **Oturai, N. G.,** Syberg, K., Fraisl, D., Hooge, A., Ramos, T. M., Schade, S. & Hansen, S. F. UN plastic treaty must mind the people – citizen involvement in plastic policymaking. *One Earth*, 6 (6) https://doi.org/10.1016/j.oneear.2023.05.017

Additional contributions and public dissemination

(VI) Syberg, K., Nielsen, M. B., **Oturai, N. G.,** Clausen, L. P. W., Ramos, T. M. & Hansen, S. F. Circular economy and reduction of micro (nano) plastics contamination. (2022) *Journal of Hazardous Materials Advances*, 5

(VII) Clausen, L. P. W., Nielsen, M. B., **Oturai, N. B.**, Syberg, K., & Hansen, S. F. How environmental regulation can drive innovation: Lessons from a systematic review. (2022) *Environmental Policy and Governance*

(VIII) Thit, A,. Grønlund, S. N., Trudsø, L. L., Hansen, B. W., Herzog, S. D., Nielsen, S. L., **Oturai, N. G.,** Posselt, D., Ramasamy, P. K., Sandgaard, M. H., Syberg, K., Selck, H., & Lyngsie, G. Particles as carriers of matter in the aquatic environment: Challenges and ways ahead for transdisciplinary research. (2022) *Science of the total environment*, 838 (2)

(IX) Nielsen, M. B., Clausen L., Hansen, S., Cronin, R., Hansen, S. F., **Oturai, N. G.,** & Syberg, K. Unfolding the science behind plastic policy initiatives targeting plastic pollution. (2023) *Microplastics and nanoplastics*, 3

(X) Ramos, T. M., Christensen, T. B., **Oturai, N. G.** & Syberg, K. Reducing plastic in the operating theatre: Towards a more circular economy for medical products and packaging. (2023) *Journal of cleaner production*, 383

(XI) *Manuscript in prep:* Hartmann, N. B., Rist, S., Syberg, K., **Oturai, N. G.**, Lisiecki, M., Logan, H., Astrup, T., Bisinella, V., Hansen, S. F. & Damgaard, A. Plastic in a context of the Triple Planetary Crisis.

Public dissemination

(XII) **Oturai, N. B.** & Syberg, K. Plast på godt og ondt. (2020) *Geografisk Orientering*, 50 (1)

(XIII) **Oturai, N. G.,** Hansen, S., F. & Syberg, K. Borgerne skal inddrages hvis vi skal plastforurening til livs. (2022) *Forskerzonen.dk*

Author contributions

(I) Research paper

All authors: Conceptualization, methodology, writing – review & editing
KS: Formal analysis, data curation, writing – original draft
SFH: Writing – original draft
NBH: Visualization
LPWC: Formal analysis
SM: Statistical analysis

(II) Research paper

NGO: Conceptualization, methodology, formal analysis, investigation, data curation, writing – original draft, visualization
KS: Conceptualization, methodology, formal analysis, writing – review & editing, supervision, funding acquisition
SP: Methodology, formal analysis, writing – review & editing

(III) Review

NGO: Conceptualization, methodology, data curation, investigation, writing – original draft, visualization
MBN: Data curation, investigation, writing – review & editing
LPWC: Data curation, investigation, writing – review & editing
SFH: Data curation, investigation, writing – review & editing
KS: Conceptualization, methodology, data curation, investigation, writing – review & editing, supervision, funding acquisition

(IV) Research paper

NBO: Conceptualization, data curation, formal analysis, methodology, writing - review & editing
LPWC: Conceptualization, data curation, formal analysis, methodology, visualization, writing – original draft, writing – review & editing
SFH: Conceptualization, data curation, formal analysis, methodology, visualization, writing – original draft, writing – review & editing
KS: Conceptualization, data curation, formal analysis, methodology, visualization, writing – original draft, writing – review & editing
OFHH: Data curation, formal analysis, visualization, writing - review & editing

(V) Research paper

NGO:	Conceptualization, methodology, investigation, writing – original draft, visualization, project administration
KS:	Conceptualization, methodology, investigation, writing – review & editing, supervision, funding acquisition
DF:	Writing – review & editing
AH:	Investigation, writing – review & editing
TMR:	Investigation, writing – review & editing
SS:	Writing – review & editing
SFH:	Conceptualization, methodology, investigation, writing – review & editing, supervision,

List of authors:

Nikoline Bang/Garner Oturai (NBO/NGO), Nanna B Hartmann (NBH), Søren Møller (SM), Kristian Syberg (KS), SP (Sabine Pahl), Maria Bille Nielsen (MBN), Lauge Peter Wester Clausen (LPWC), Steffen Foss Hansen (SFH), Oliver Foss Hessner Hansen (OFHH), Dilek Fraisl (DF), Asta Hooge (AH), Tiffany Marilou Ramos (TMR), Sven Schade (SS)

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I want to extend a sincere thank you to the MarinePlastic Center and the Department of Science and Environment of RUC for creating an outstanding academic learning and working environment - for the funding and opportunity for me to conduct my Ph.D. Thank you to the organizational superhero that is Birgitte – the number of questions that I have sent, and that you have responded to, is unbelievable and I owe you great thanks for always making me and my fellow Ph.D. colleagues feel administratively looked out for.

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Luka, and Hannah – this is for you. I hope and wish for you to experience the miracle of environmental recovery in your time.

Preface

The current plastic pollution crisis is complex, and thus, the solution cannot be simple either. Working with plastic waste prevention and mitigation is inherently a tremendous task, inducing great realization of the need for immediate and effective action from multiple sides. Establishing a holistic approach to the research field has for me meant seeing not only regulatory or technical solutions to the present issues but insisting on including the societal aspect and human agency. Central to that argument is acknowledging that shifting away from the current unsustainable structures must not only be a regulatory responsibility, nor is it the individual's burden – it is a collective effort. In this thesis, I operate with a threefold approach that incorporates a scientific, social, and policy dimension to plastic pollution and the immediate challenges of advocating fundamental changes when prevailing structural forces are the mainstay in society.

With a foot in both camps - the natural and social sciences - I appreciate the advantages of tackling problems from multiple angles and thus, the citizen science methodology stands as a basis for my research embodying elements from environmental, policy, and behavioral sciences. The interdisciplinary approach of citizen science in working with plastic pollution has experienced public support globally and attests to a large segment of citizens eager to go out and act on a scientific premise against plastic waste. Naturally, citizen science cannot stand alone in lifting the heavy weight of the pollution problem. Yet, at this moment, the public voices their concerns, and a bigger movement toward a shift in the way we produce, consume, and dispose of plastic products is taking form, to which this research seeks to contribute.

Acknowledging my position as the knowledge producer in this interdisciplinary context, and the fact that no scientific conduct, however, controlled, or transparent, can stand un-situated, I affirm my position and accountability of the research conducted in and for this thesis. Still, in the light of the highly collaborative manner that I have been brought up with in my research group at Roskilde University, and in MarinePlastic as well, this thesis will predominantly use a recurring "we" that seeks to acknowledge the great collaboration and inclusiveness I have experienced in the past years - a research environment that I am very proud to be a part of.

SAMMENFATNING (DK)

En verden uden plast er utænkelig. I løbet af det foregående århundrede har plast gennemsivet det moderne samfund med dets hidtil usete evne til at skabe adgang til og forbedre levestandarden for mange mennesker. Imidlertid har produktion, anvendelse og afskaffelse af plastprodukter vist sig at have skadelige konsekvenser for miljøet på et globalt plan, samt potentiels udgøre en sundhedsrisiko for mennesker og dyreliv. Det voksende forskningsfelt for plastforurening er optaget af at afdække centrale videnshuller heriblandt; videnskabelig evidens vedrørende mængder, udbredelse og effekter. I løbet af de forrige årtier har plasthåndtering gjort sit indtog på den politiske dagsorden, hvilket bl.a. har ført til nationale lovgivninger og samarbejder på tværs af kontinenter, f.eks. i den Europæiske Union (EU), og helt aktuelt i De Forenede nationer (FN) med vedtagelsen af den kommende FN-traktat vedrørende plastforurening. Citizen science er en tværvidenskabelig metode, der muliggør samarbejde med almindelige borgere gennem videnskabelige projekter hvorved der opstår et trefoldigt potentiale for at; producere robust videnskabelig evidens; have påvirkning på sociale faktorer såsom miljøvenlig adfærd og; have politisk indflydelse. Denne praksis har fået fodfæste indenfor miljøvidenskab og bliver bl.a. brugt til at monitorere plastforurening, særligt i kystnære og marine omgivelser.

Med udgangspunkt i det omtalte tredelte perspektiv, er denne afhandling forankret i et tværfagligt felt, der støtter sig op ad elementer fra både natur- og samfundsvidenskaben. Gennem fem forskningsartikler undersøger denne Ph.d.-afhandling; (a) hvordan citizen science projektet Masseeksperimentet 2019 kan sammenholdes med traditionelle monitoreringsprogrammer, (b) hvordan man kan studere de sociale effekter af citizen science projekter med udgangspunkt i en spørgeskemaundersøgelse af deltagerne i Masseeksperimentet, og (c) hvordan citizen science kan spille sammen med politiske beslutningsprocesser. Resultaterne peger bl.a. på vigtigheden af at anerkende de videnskabelige rammer for hvert forskningsfelt ved udviklingen af citizen science aktiviteter der stiler efter at opnå videnskabelig, social og politisk indflydelse. Vi finder at harmonisering og overholdelse af videnskabelige protokoller er afgørende for data integration og vidensdeling (artikel (I)), mens der bør rettes opmærksomhed mod deltagerinddragelse, og særlige indikatorer for adfærd for at forstå adfærdsændringer og andre sociale effekter af citizen science deltagelse (artikel (II) og (III)). Artikel (IV) illustrerer bl.a. at den aktuelle borgerinddragelse i den Europæiske plast-regulering er ineffektiv. Dette bliver udfoldet i artikel (V), som også undersøger hvordan citizen science potentielt kan muliggøre indflydelse på alle stadier i en EU reguleringsproces. Afslutningsvis fremstiller vi en række anbefalinger til, gennem citizen science, at løfte den politiske borgerdeltagelse i udformningen af FN-traktaten om plastforurening.

Abstract

A plastic-free world is unimaginable. During the past century, plastics have entangled modern society with an unprecedented ability to improve and enable the living standards of people. Still, the production, use, and disposal of plastics come with high costs for the global environment and pose potential risks to animal and human health. The plastic pollution research field is growing continuously in the quest to close central knowledge gaps, including evidence on the abundance, distribution, and impacts. Managing plastics has in recent decades made its entry on the political agenda leading to national legislations and coalitions across continents, for instance in the European Union (EU) and most recently, in the United Nations (UN) with the endorsement of a coming UN Treaty on plastic pollution. Citizen science is a interdisciplinary method for inclusion and cooperation with citizens in research projects and holds a threefold potential of, producing solid scientific outcomes, having pro-environmental social effects, and influencing policy. The practice has gained footing in environmental sciences and has been used to monitor plastic pollution, particularly in coastal and marine environments.

Based on the threefold perspective, this Ph.D. is rooted in an interdisciplinary setting, drawing on theory and methods from the natural, behavioral, and political sciences. Through five papers this thesis explores (a) how the citizen science project, the Mass Experiment 2019, can compare to traditional monitoring programs, (b) how to study the social effects of citizen science projects based on a survey study of participants in the Mass Experiment, and (c) how citizen science may translate into policy.

The results of our studies among other things point to the importance of acknowledging the scientific boundaries and possibilities of each research field when designing citizen science projects for potential scientific, social, and political influence. Harmonization and adherence to advancing scientific protocols for monitoring and assessments are pivotal for data integration and knowledge dissemination (paper (I)), whereas attention to participant involvement and particular predictors are central to understanding behavior changes evoked by citizen science activities (papers (II) and (III)). Paper (IV) demonstrates the inefficiency of representing the citizen stakeholder group in the current European plastic pollution policy. This is further unfolded in paper (V), which also examines how citizen science can potentially influence all stages in the EU policy process. We eventually provide recommendations for increased public participation through citizen science in the development of the UN plastics treaty.

CHAPTER 1. INTRODUCTION

1.1. A triple planetary crisis

In 2020 the United Nations Environment Programme (UNEP) issued a report on the current state of the relationship between people and the planet declaring a "triple planetary crisis". The focus was directed on the three major threats to the Earth system as we know it: Climate change, loss of biodiversity, and pollution (The Triple Planetary Crisis, 2020). Societies worldwide and the general environment pay an immense prize for the consequences of the "toxic trail of economic growth" in the forms of unsustainable extraction of natural resources combined with vast (and growing) consumption and waste patterns (MacLeod et al., 2021; UNEP, 2021; Velis & Cook, 2021). As such, the "triple planetary crisis" will stand as the core element of UNEP's next five-year strategy with science as the catalyst for action (The Triple Planetary Crisis, 2020). Zooming in on one of the three pillars of the crisis, pollution, and then more specifically on plastics, research has proven time again that decades of obliviousness, and excessive plastics consumption, have created vast amounts of plastic waste ending up in the natural environment to degrade further into micro- and nano plastics with unknown effects on ecosystems all around the globe (GESAMP, 2015; MacLeod et al., 2021; OECD, 2022; Ryberg et al., 2019).

My thesis suggests a holistic perspective to gain insights into the interplay between policy, people, and the environment when targeting plastic pollution. Plastics are visible and ubiquitous pollutants in the environment which, combined with recent policy focus and media attention, cause great concern in the general public (Catarino et al., 2021; Felipe-Rodriguez et al., 2023; Henderson & Green, 2020; SAPEA, 2019). A recent survey study by Davidson *et al* (2021) attests to the public across 15 countries being "extremely concerned over human health impacts of marine plastic pollution" and emphasizes strong support for research on plastic pollution. At that, the attention to citizen science, which is an interdisciplinary method for involving people in scientific research, falls as a natural starting point for this research.

The continuous failure to sustainably manage plastics was emphasized during the COVID-19 pandemic. The coronavirus gave rise to an enormous increase in single-use plastic (SUP) products in the name of hygiene and with direct consequences for the environment (Ammendolia & Walker, 2022a; Peng et al., 2021). Simultaneously, during the pandemic, the capacity of citizen science as a means to collect and analyze COVID-19-related plastic litter data with the help of average citizens flourished and thus demonstrated the potential of citizen science to bring new and unknown empirical research areas to light (Ammendolia et al., 2022; Ammendolia & Walker, 2022a; France, 2022; Shruti et al., 2022).

1.2. The path of plastics

As the existence of plastic material is entirely a manmade phenomenon, human behaviors play a significant role in all aspects of the plastic life cycle including the production, consumption, and disposal of plastic products (Pahl et al., 2017; Ross, 2018). The flow of plastics in the current system is characterized by embedded flaws causing the material to escape to the environment (OECD, 2022). That human action is the main driver of plastic pollution stands clear as plastic production is constantly increasing in concert with the growing world population, industry, and demand for resources (OECD, 2022; Plastics Europe, 2022; Ross, 2018).

The same interdependence applies when one follows the path of plastic materials through the system, from the extraction of raw materials, manufacture, and supply of plastics in the economy; through to use and disposal in society; and onto incineration, recycling, or accumulation in the environment (Bergmann et al., 2015; SAPEA, 2019). One example of the malfunction of the current system is the low price of plastics (e.g. extraction, manufacturing, and retail) that does not reflect the true cost of impacts on the environment and consequently, there is little incentive to keep plastics in the economy and multiple ways for the material to escape into the environment (Newman et al., 2015).

The Science Advice for Policy by Academies (SAPEA) report (2019) on microplastics in nature and society describes the complex and intertwined flow of plastics with particular attention to the areas of potential change by human decisions, be it political, economic, social, etc. That depiction sparked the inspiration for Figure 1 which highlights the major pathways of plastics throughout the lifecycle including the structural flaws of the system and further serves as the foundation on which this thesis takes its offset.

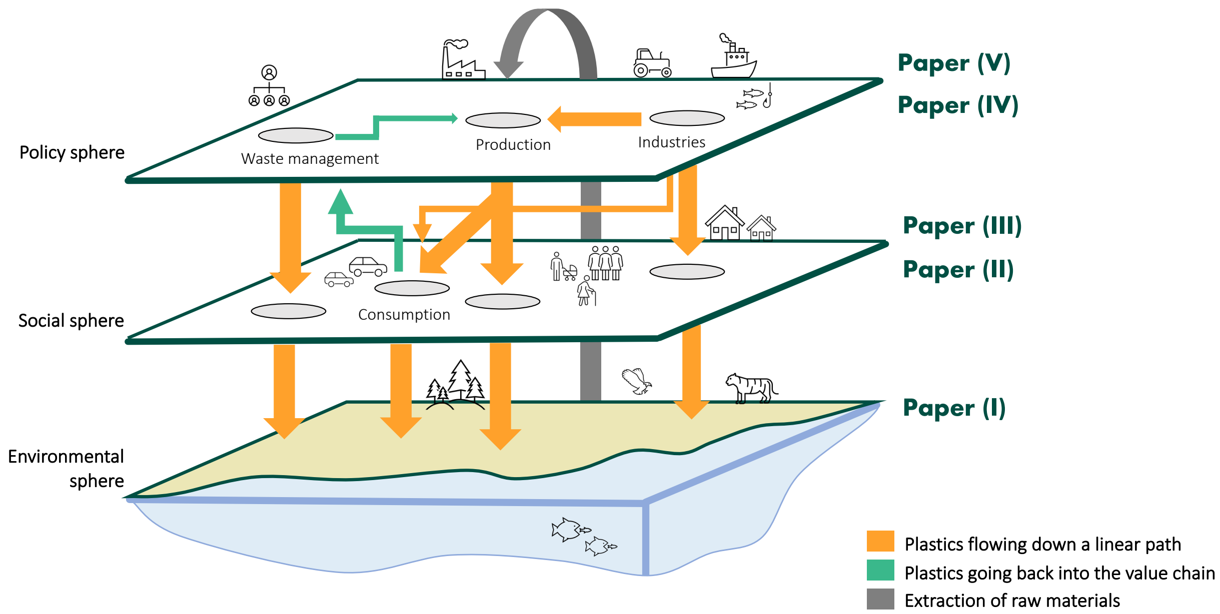


Figure 1: A simplified presentation of the path of plastics illustrating the threefold approach of this thesis. The path begins with the extraction of raw materials, production, and management in the top sphere, then moves through to society affected by use, and waste behaviors, eventually reaching the environment. Inspired by GRID Arendal (2021) and SAPEA (2019).

In the "policy" top sphere, the general direction for action is determined including; the extraction of raw materials; the legal frameworks for production, the industry as well as waste management throughout the plastic lifecycle (Bergmann et al., 2015). Subsequently, plastic products and waste from the economy (such as virgin plastic pellets, textiles in wastewater, tire wear from transportation, etc.) pass through to the middle layer representing the "social sphere" (Bergmann et al., 2015). Here, citizens use consumer goods and subsequently dispose of them either correctly (through organized waste systems or recycling) or incorrectly by accidental or intentional littering (OECD, 2022). Beneath the societal structures, the final endpoint for plastic waste leaked from above, caused by systemic flaws, is the "environmental sphere". Plastic materials will typically accumulate here in landfills, be washed out or carried by the wind to sea, enter the ecosystems, and eventually degrade into smaller pieces with little-known effects on fauna and human health (UNEP et al., 2021).

It is important to underline that even though management, production, consumption, and disposal are dependent on human behavior, systemic plastic pollution is not the responsibility of people as individuals. There is little one person can do to change or go against generations of locked-in systems and industries that depend on plastic. Rather, systemic change requires advances that are multifaceted and inclusive of all stakeholders to be effective (Bäckstrand, 2006; CIEL, 2022; Löhr et al., 2017; Walker & Fequet, 2023; Zheng & Suh, 2019).

In my research, I have approached plastic pollution through the lens of citizen science. I am concerned with how citizens can add to the solution to the ubiquitous plastic pollution by playing an active part in the scientific practice of citizen science. By contributing to filling in critical knowledge gaps of plastic pollution monitoring (Fraisl et al., 2022), citizen science offers a platform for amplified participation with positive implications for legitimacy and effective policy implementation (Turbé et al., 2019). Additionally, participation in science production suggests increased awareness, concerns, and possible behavior changes, which in turn may play a crucial part in directing the general discourse on plastic pollution and pushing the environmental agenda for decision-makers. As depicted in Figure 2, the five papers presented in this thesis work with the threefold potential of citizen science in all three spheres from the bottom in the environment (paper (I)), through society (papers (II) and (III)), moving up to the political arena where decision-making takes place (papers (IV) and (V)).

1.3. Research objective and aims

Approaching the overarching objective of how the threefold potential of citizen science, can play a role in reducing plastic pollution, I work with diverse aspects and methodological frameworks (cf. Figure 2). The main direction and deliberations of my thesis will be three-part based on the following aims:

a) How do citizen science monitoring activities compare to traditional monitoring methods?

b) How can we study and encourage the social implications of participating in citizen science projects?

c) What are the challenges and opportunities for citizen science to translate into policy?

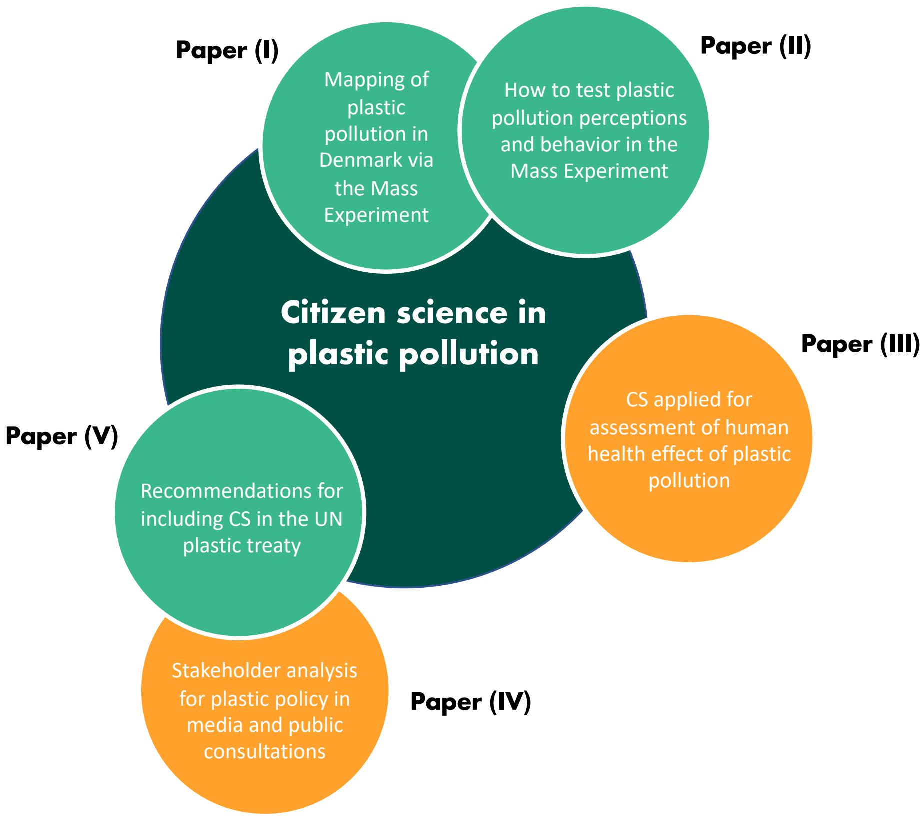


Figure 2: *A thematic overview of the scientific contributions. Papers (I), (II), and (V) leading the thesis storyline are marked with light green, while papers (III) and (IV) supporting the narrative are orange. CS: Citizen science.*

Paper (I) presents the comprehensive citizen science project, the Mass Experiment 2019, involving Danish school children. Here we applied citizen science as a scientific methodology to monitor and map plastic pollution in the Danish environment. We further wanted to study the behavioral effects of the Mass Experiment 2019 and thus paper (II) explored how to measure the change of perceptions and pro-environmental behaviors of the participants studying selected psychological variables before and after the intervention. Later, and unrelated to the Mass Experiment, I attended to the potential of employing citizen science methods for plastic pollution monitoring outside of the environmental field. Possible human health effects of plastic pollution are triggering public concerns and therefore we, in paper (III), focused more specifically on exploring the potential of citizen science for measuring plastic pollution exposure to human health in a current review article. In paper (IV), we conducted a stakeholder analysis related to European plastic policy, which among other things, made it clear that the citizen stakeholder was not represented in the public hearings in focus. These findings turned my attention toward how to effectively include citizens in plastic policymaking using citizen science. Consequently, in paper (V) we analyzed citizen participation and policy impacts in selected plastic regulations of the European Union (EU), and based on these lessons, the research provided recommendations for the development of the upcoming United Nations (UN) plastic treaty.

Chapter 2: Theoretical background

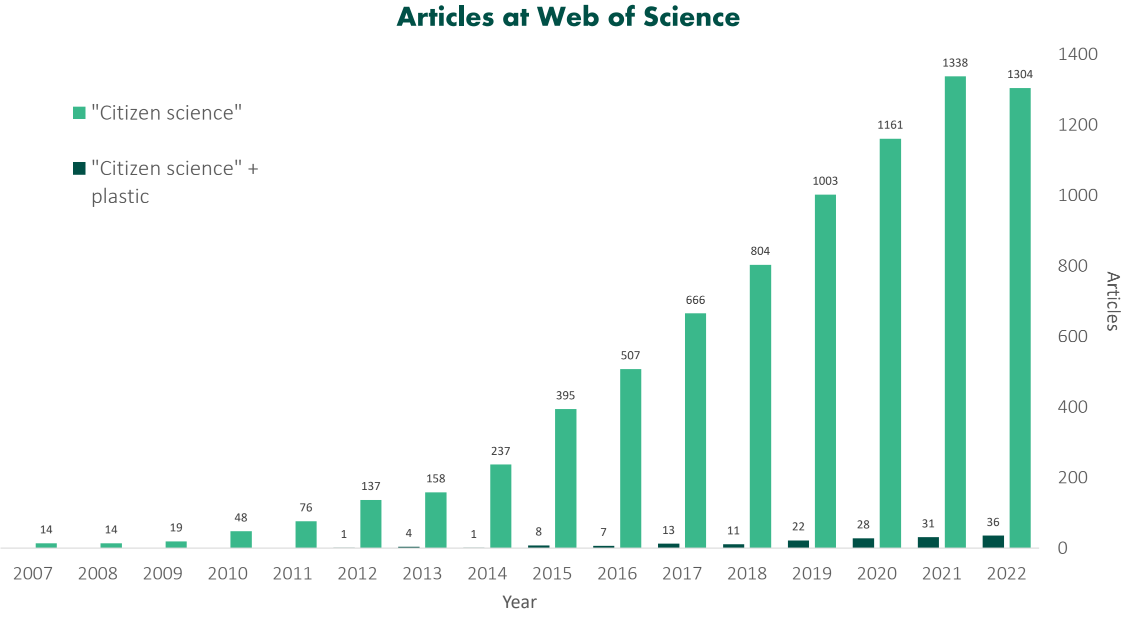
To fully explore the threefold capacity of citizen science, three main elements of theoretical and contextual nature must be established. First, an introduction to the science of citizen science provides an overview of the research field and how the method is relevant and applied in environmental science with a focus on plastic monitoring setting the scene for paper (I). Next, the topic of citizen science concerning social processes, environmental behaviors, and young participants, as presented in papers (II) and (III), is described. Finally, the state of public participation in plastic pollution policy - relevant for papers (IV) and (V) - is presented to explore how citizen science outcomes have been embedded in a policy perspective.

2.1. Citizen science and plastic pollution

Citizen science encompasses a wide range of ways for researchers to work alongside the public on small or large-scale projects to uncover and change a scientific problem (Vohland et al., 2021). As a descendant of the broader fields of *community-based research* and *participatory research*, citizen science today exists as a practice in its own right (Cornwall & Jewkes, 1995; Göbel et al., 2021). Across scientific disciplines, citizen science encourages regular citizens to collaborate with science professionals through different stages in research projects that are characterized by having a scientific output set to make a change of either political, conservational, or informational kind (ECSA, 2023). The European Citizen Science Association (ECSA) defines citizen science through 10 principles for good practice, including citizen involvement, science outcome genuineness, and citizen data access, thus establishing a common ground for practitioners and participants to operate within a common framework (Robinson et al., 2018).

2.1.1. Citizen science

The application of citizen science methodologies in research has proven to be vast and to



a great extent within fields where the power of observations is paramount for scientific advancements such as in ecology, bio conservation, astronomy, etc. (Silvertown, 2009). The methodology is, however, expanding into other areas, for instance in medical research where the overarching interest for human health effects is a strong fundament for citizen engagement (Davison et al., 2021). Citizen science is a relatively novel term in the academic literature although citizens - within the above-mentioned fields - for decades have recorded facts about the natural world around them for personal interests and as research contributions (Berti Suman & Alblas, 2023; Louv & Fitzpatrick, 2015; Vohland et al., 2021).

Figure 3: *Results from Web of Science for search terms "Citizen science" and "Citizen science" + "plastic". No results were found for "Citizen science" + "plastic" before 2011. Less than eight hits were found per year for "citizen science" between 2001 and 2007, and no results before that.*

The relatively newfound employment and entry into published science of citizen science, as depicted in Figure 3, can partially be owed to the technological developments of the last 20-30 years. The fastmoving digitalization and access to the Internet have largely allowed people from all types of social and demographic positions to disseminate information, gain knowledge and feed into regional and global databases through smartphones (Bonney et al., 2014; Garcia-Soto et al., 2021; Silvertown, 2009). Consequently, citizen science-generated data has increasingly assisted in covering knowledge gaps that rely heavily on the participation of a large number of people, including communities with vital local and indigenous knowledge (Luzar et al., 2011; Tengö et al., 2021). Environmental monitoring of plastic pollution, mainly of macro-size (>5mm (Merga et al., 2020)), through citizen science has since 2011 emerged as a separate discipline in the academic literature and although the published literature hereon remains modest in numbers it is rapidly growing (cf. Figure 2). In this thesis, I briefly highlight the spreadability - the opportunity to implement citizen science methods in fields beyond the environmental - regarding plastic pollution (paper (III), as many are yet unexplored.

2.1.2. Citizen science and environmental monitoring of plastic pollution

Given that plastic debris in the environment has a plethora of sources (cf. Figure 1) and characteristically gets transported across large spaces by wind or other forces of nature, the waste can end up in entirely different places than its origin (UNEP et al., 2021). Understanding the true proportions of plastic pollution, and offering effective responses, require in-depth assessments of spatial and temporal trends regarding sources, pathways as well as consumer and littering behaviors, which can be obtained through monitoring (Fraisl et al., 2022; GESAMP, 2019; Subramanian, 2022). Global and regional actions to collect, assess and coordinate data on marine litter are already being employed by different actors with sometimes diverging methodologies (e.g. in terms of methods and application areas, etc.) some of which include citizen science data (UNEP, 2021). As a result, comprehensive guidelines have been published to support and ensure scientific consistency, comparability, and quality of monitoring data, for instance, the International Council for Exploration of the Sea (ICES) (2013), the Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP) (2019), and the Oslo-Paris agreement (OSPAR) (2010), that are working towards increased data integration and implementation of current legislation including the Marine Strategy Framework Directive (MSFD) under the European Union (EU). On a national level systematized monitoring of marine pollution has for instance been conducted on Danish reference beaches three times annually since 2015 by the Danish Centre for Environment and Energy (DCE) (Feld et al., 2020). By employing and perhaps slightly modifying (in case of specification) consistent methods, e.g. codes for litter classification, the survey results can be directly translated into OPSPAR, the United Nations Environmental Programme (UNEP), or MSFD context.

Apart from the quantitative scientific outcomes of the monitoring and assessments that traditional methods encompass, involving citizens in several or all steps of a citizen science monitoring project may create advances to otherwise inaccessible knowledge; a high quantity of observations; as well as geographical and temporal coverage, which holds relevance for plastic pollution. By nature, citizen science monitoring programs differ from traditional monitoring programs and are equally diverse among themselves. Yet, they typically adhere to the same process depicted in seven steps in Figure 4, whereas steps 1, 6, and 7 are especially distinctive for citizen science in comparison to traditional methods.

Figure 4: Seven steps that citizen science monitoring programs typically have in common. Inspired by Tredick et al (2017), graphics are own work.

Minding that participants in any citizen science project are considered non-experts, resources should be allocated for; bias-checking e.g. by triangulation across data, participants, and methods; producing training materials; in-situ guidance before and during (if possible); and easily comprehensible protocols including information on study sites measuring, identification of plastic types and reporting (Aceves-Bueno et al., 2017; Danielsen et al., 2021; Fraisl et al., 2022; GESAMP, 2019; Kosmala et al., 2016). Importantly, motivation for engaging and retaining volunteer participants in citizen science projects among other things includes clear and comprehensible communication throughout the process (West & Pateman, 2016). To demonstrate the application and assessment potentials of citizen science Table 1 non-exhaustively displays key characteristics of plastic pollution citizen science monitoring projects inspired by UNEP and GRiD Arendal (2021).

Table 1: Presentation of typical characteristics of citizen science monitoring projects for plastic pollution with input from i.a. Syberg et al (2020), UNEP (2021), and Fraisl et al (2022).

Why e.g.	**What**	**How**	**Where**	**Who**	**When**	**Results**
Source ID	Quantity	Collections	Marine	Volunteer groups	Single survey	Open data
Types of litter	Polymer type	Observations	Costal	Private groups	Repeated survey	Policy guidance
Fate	(Macro)size		Riverine	Target groups:		Scientific output
			Urban	E.g. Youth, indigenous peoples		Local knowledge generation

Following the monitoring activities, data from official projects are typically stored in open repositories (cf. Tabel 1, and step 5 in Figure 4). Next analyses and statistics are usually carried out by the collaborating experts while data quality assurance checks simultaneously should be performed, before finally communicating and publishing results in scientific journals or otherwise disseminated in formal or informal networks/settings (e.g. reports, grey literature, etc.) (Vohland et al., 2021). Lastly, the evaluation of the activity and outcomes produce insights that are relevant for a possible recurrence of the project (cf. step 7 in Figure 4) (Tredick et al., 2017). It was in this context that we co-designed the Mass Experiment 2019 (paper (I)), drawing from; the, at the time, reduced experiences with general data quality assurance (Kosmala et al., 2016); biases in datasets (Bird et al., 2014); and the extensive knowledge and longstanding partnership with the participant group by the Mass Experiment organizer, the National Center for Learning in Science, Technology, and Health in Denmark, Astra.

2.2. Citizen science and social implications

2.2.1. Behavioral implications of citizen science activities

Regarding environmental fields that are steered by human actions, such as plastic pollution, understanding pro-environmental behaviors (PEB) as well as what prompts and predicts these are necessary (Nuojua et al., 2022; Pahl et al., 2017). PEBs are defined as behaviors that "actually contribute or are perceived to contribute to environmental conservation", whereas the practice of environmental conservation is determined as actions that either contribute to a reduction of negative impacts, or promotion of positive impacts on the environment (Kurisu, 2016). Although pervasive societal knowledge and awareness such as information campaigns are commonly used (e.g. by authorities), and indeed are central for raising attention to environmental issues, these rarely lead to concrete changes in behaviors (Abrahamse & Steg, 2013; Heidbreder et al., 2019; Kaiser & Fuhrer, 2003; Nuojua et al., 2022).

In the environmental psychology literature, antecedents for PEBs (apart from knowledge) include, but are not limited to; *risk perception* and *concern* (Bak, 2018; Felipe-Rodriguez et al., 2023; Liobikiene & Juknys, 2016; Syberg et al., 2018); *attitudes* (Ibrahim et al., 2021), *values* (Nuojua et al., 2022; Prakash et al., 2019); *social norms* (Borg et al., 2020; Grønhøj & Thøgersen, 2012; D. T. Miller & Prentice, 2016); *self-efficacy* (Bandura et al., 1999; Tabernero & Hernández, 2011); *empowerment* (Hamilton et al., 2022; Turreira-García et al., 2018); alongside various sociodemographic variables such as *income level*, *gender*, *ethnicity*, and *geographical location* (Berenguer et al., 2005; Braun et al., 2018; Ifegbesan & Rampedi, 2018; Soares et al., 2021). When designing political and psychological interventions that aim to encourage behavior change, the broad and interplaying range of predictors for PEBs is thus central to acknowledge (Nuojua et al., 2022). Knowing this, we decided to conduct a voluntary meta-study, paper (II), running parallel with the Mass Experiment 2019, exploring how to measure behavior changes in the young participant group attending to several of the abovementioned PEBs (cf. section 3.2.3.).

Contrary to claims of citizen science activities merely conducting palliative and Sisyphean actions to a pollution problem that extends far beyond cleaning up nature sites, there are additional and widespread potentials for involving citizens in science practices. Methods for measuring effects are progressing and growing in numbers, yet systematic evaluation of learning, behavioral and psychological outcomes of citizen science projects are still understudied (Heidbreder et al., 2019; Mayer et al., 2022; Nuojua et al., 2022;

Somerwill & Wehn, 2022). Participation in citizen science projects has, among other things, shown indications of; awareness raising, environmental learning, increased environmental concern, and civic participation (Felipe-Rodriguez et al., 2023; Kramm & Völker, 2023; Peter et al., 2019; Syberg et al., 2020; Turrini et al., 2018). Thus, the proposed capacity of citizen science reaches well beyond data collection and into the social domain, where the interplay between citizens, science, and policy is positioning the participatory research methodology of citizen science as an interesting and opportunistic fit (Nelms et al., 2022). For instance, while the effects of plastic pollution are not yet fully understood on ecosystems, and even less regarding human health, the concern level of the public is significant, posing as a potential catalyst for increased policy and science focus (Bertsou & Caramani, 2022; Davison et al., 2021) as well as a direct opportunity for involving participants in scientific research (West et al., 2021).

2.2.2. Children, youth, and environmental behaviors

Encouraging PEBs for not only adults but also children and youth is important to ensure long-term environmental protection as young people are shown to be agents of sustainable change (Hedefalk et al., 2015; van de Wetering et al., 2022). Children are the next generation of consumers, voters, decision-makers, and parents, and therefore the importance of teaching environmentally conscious behaviors to children and young adolescents is widely acknowledged (UN, 2015). Environmental education in early childhood has proven to influence behaviors later in life (Evans et al., 2007, 2018), whilst also positively affecting the pro-environmental household behavior, values, and knowledge of their parents (Damerell et al., 2013; Knafo & Galansky, 2008; Kusumawati et al., 2020).

The link between science learning outcomes and citizen science is yet to be fully explored, nevertheless, the growing evidence base suggests positive feedback loops between educational activities in science (e.g. citizen science projects) and increased scientific identity and agency (Ballard et al., 2018; Edwards et al., 2019; Pandya & Dibner, 2018). Focusing in on plastic pollution, Hartley *et al* (2015a) found that a marine litter education intervention aimed at British school children changed the concern level; knowledge of sources and impacts; as well as self-reported litter-reducing behaviors (Kormos & Gifford, 2014). Correspondingly, citizen science projects with educational as well as monitoring aims with participants in the school-age range have been successfully facilitated across different continents including, Europe, South America, Asia, and Africa, adding to the growing literature on plastic pollution and marine litter interventions with young participants (Catarino et al., 2023; Honorato-Zimmer et al., 2019; Kiessling et al., 2019, 2021; Syberg et al., 2020).

2.3. Citizen science in policy

2.3.1. Trust in the European Union and environmental action

The EU is built on democracy and so the backing of the people is necessary to support the elected representatives' political decisions on their behalf (Kriesi, 2020). Meanwhile, research shows that current, official channels for involving European citizens in environmental policymaking, including public hearings, polls, and petitions, are in many ways a work in progress (Hierlemann et al., 2022). Generally, citizens' trust in the EU has been strained during recent years' economic and political crises (e.g. causing Brexit in 2017) leading to public reproach (Berg, 2019). Literature reveals that European citizens, and especially the younger generations, feel increasing news fatigue, alienation, and powerlessness toward the EU's capacity to create necessary changes concerning the impending environmental and climate crises (Dahl et al., 2018; Motti-Stefanidi & Cicognani, 2018).

Within the field of environmental protection, similar to the climate change protests led by e.g. Gretha Thunberg and Extinction Rebellion, trends of the public taking initiative outside of traditional policy participation are seen with increasing environmental stewardship practices in local communities. For instance, by volunteer planning and participating in beach and nature clean-ups (Jorgensen et al., 2021; Pickard, 2022). Different from the abovementioned protesting forms of climate activism, the groupings of citizens in organized pro-environmental projects and campaigns typically operate within a scientific framework, as seen with community-based citizen science projects (Soares et al., 2021). Here the citizens' practical contributions have significance through personal experiences in addition to the local change and the scientific data produced, which often hold the potentials to inform policymakers (Hartley et al., 2018; Jorgensen et al., 2021; Nelms et al., 2022).

2.3.2. Citizen science uptake in policy

By now the potential of citizen science as a contributor to political decision-making has gained attention at various governance levels, including in the EU (EC, 2023; Figueriredo N. et al., 2016; Schade et al., 2017, 2021), however the experiences with actual incorporation and application of citizen science in policymaking is still limited (Bio Innovation Service, 2018; Turbé et al., 2019). The formal linkages and cooperation between informal community or NGO-lead initiatives, as well as expert-driven citizen science projects, and governmental parties, are missing among other things due to a lack of communication of policy needs, research findings, and clarification of the necessary scientific excellence (EC, 2020; Olen, 2022; Turbé et al., 2019).

Attesting to some level of governance readiness for cooperation, the European Commission (EC) published a report in 2020 emphasizing the potential of environmental citizen science for policymaking and include recommendations for; bridging knowledge needs for policy; raising awareness and trust; promoting data quality, standards, and sharing tools, and; supporting cooperation (EC, 2020). Also under EU auspices, the Joint Research Centre (JRC) has explored the *scalability* (the upscaling of existing practices to larger capacities) and the *spreadability* (the replication of a practice from one place to another) of citizen science activities, and proposed a framework for enabling constructs that include how to create citizen science projects that are scalable by design; assess scalability in existing activities and how to frame future research initiatives to explore scaling of citizen science (Maccani et al., 2020).

From an early onset, questioning the data quality of citizen-collected and reported data has been a principal concern for policymakers and other stakeholders. Nevertheless, as previously mentioned, researchers along with citizen science practitioners have been dedicated to developing methods that ensure validity and reliability, and proven many times over that datasets from citizen science projects can be compared to those of expert scientists (Balázs et al., 2021; Fraisl et al., 2022; Kosmala et al., 2016; Kramm & Völker, 2023). Some of the most essential steps to ensure data trustworthiness include; systematic and scientific protocols that are approachable for non-scientists; iterative project development; volunteer training; and statistical models of systematic errors (Kosmala et al., 2016).

Research on the application of citizen science data for policy uptake highlights intentions and vague aims of policy impacts from many citizen science practitioners with scarce evidence of the actual policy impacts. The potentials are nevertheless vast as citizen science projects have been proven able to inform steps throughout the full policy cycle and, with the right policy communication and cooperation, these activities can be a participatory, cost-effective, and multi-use source of, in this instance, plastic pollution data (Schade et al., 2017; Turbé et al., 2019).

2.3.3. In a global policy perspective

In recent years, researchers have advocated the relevance of citizen science as a method for reporting the Sustainability Development Goal (SDG) indicators across the goals and thus as a resource of high-level policy significance (Fraisl et al., 2020; Fritz et al., 2019). Fraisl *et al* (2020) successfully applied citizen science methods as an official data source for monitoring SDG progress in Ghana in cooperation with the Ghanaian government (Olen, 2022). Not only did the citizen science data collection and reporting feed into the national database for SDG monitoring but on a local scale the monitoring activities increased an understanding of the environmental effects of the COVID-19 pandemic as well as the necessary policy actions towards marine plastic pollution (Olen, 2022).

Ultimately, in the spring of 2022, the United Nations Environment Assembly (UNEA) was, along with the world's leaders, able to reach a historic consensus on a global treaty to end all plastic pollution (UNEP, 2022). The agreement on developing a legally binding plastics treaty is not confined to viewing plastic pollution as a waste problem but rather an issue that needs to be tackled throughout the entire lifecycle. As the intergovernmental negotiations on the treaty have already been initiated, researchers from different scientific fields have weighed in on what the treaty ought to entail (Ammendolia & Walker, 2022b; Bergmann et al., 2022; Rognerud et al., 2023; Syberg, 2022; Thompson C. et al., 2022; Vitorino et al., 2022). In a speech to the Open Ended Working Group to end plastic pollution, Inger Andersen, Executive Director of the United Nations Environment Programme, called for a multi-stakeholder dialogue as one of her five central recommendations for the negotiations included the civil society, indigenous peoples, youth and the informal sector (Andersen, 2022). Conclusively, exploring the potential for citizen science to elevate the citizen stakeholder participation in the development and implementation of the plastic treaty, is what we aim to do with paper (V).

Chapter 3. An Interdisciplinary methodology

As a reflection of the interdisciplinary capacity of citizen science as a research field, this work encompasses different approaches to citizen science that all play central roles in plastic pollution. Hence, this thesis operates with elements from several (and overlapping) epistemologies in natural science as well as the social sciences of policy and psychology depicted in Figure 5 below. The current chapter will account for the principal research methods that have been employed throughout the becoming of my Ph.D., with a particular focus on papers (I), (II), and (V). These three papers have steered the central thesis narrative (cf. Figure 2) where paper (I) represents a typical citizen science monitoring project; paper (II) explores the behavioral effects of the participants in the same citizen science project; and finally, paper (V) studies the applicability of effectively incorporating citizen science in a global policy perspective, and specifically for the coming UN plastics treaty. Paper (IV) supports the methodology in paper (V) and is examined accordingly, while paper (III) which is a current literature review, plays a minor role in terms of setting the methodology scope and will not be expanded on here.

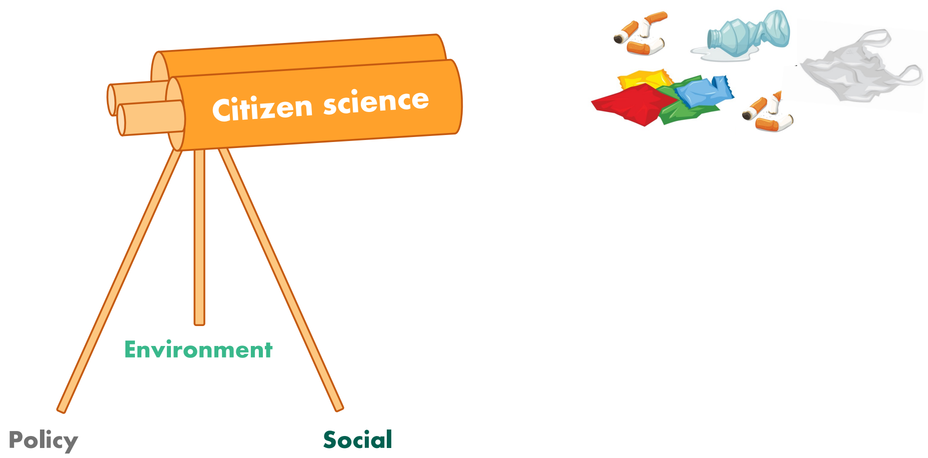


Figure 5: *Overview of this thesis' methodological approach to plastic pollution; seen through citizen science, rooted in three different research fields. Here illustrated as a tripod-binocular. Own work.*

3.1. Establishment of concept – citizen science in this thesis

Before diving into the specific methods employed for this thesis, I want to clarify the use of *citizen science* as a methodological concept throughout the rest of the thesis. *Participatory research* - an umbrella category under which citizen science falls (Albagli & Iwama, 2022; Kondo et al., 2019) - confronts the established ideas of *who* can produce scientific knowledge, *what* is studied, *where* it takes place, *how* it is produced and even *why* (Strasser et al., 2019). In this way, science production is not only open to the participating public but also the coproduction of what we know about the world. Essentially, it is the coproduction of science and society at once. As already highlighted citizen science covers a broad practice of citizen involvement in one or more stages of a project with particular scientific outcomes (ECSA, 2023). Individuals or communities can thus contribute to very different parts of a particular project which in turn may impact the participants or projects in various manners, e.g. in terms of the project aims and prioritization, fostering behavioral changes or *environmental citizenship* (Hadjichambis et al., 2020), and most importantly access to community-specific knowledge (Eicken et al., 2021; Van Oudheusden & Abe, 2021). It is here pertinent to mention *top-down* and *bottom-up* approaches to citizen science and the obvious significance either of them can have for a given project. At one end of the spectrum, we find the grassroots *bottom-up* type of project in which citizens mobilize scientific data to address local needs, as described and discussed at an early point by Alan Irwin (1995). On the other end, a direction defined by Richard Bonney (1996) viewed citizen-collected data for experts and scientific projects as the main objective. And then, certainly, there are all the variations in-between. Typically, *bottom-up* projects are characterized by being smaller, citizen-driven, do-it-yourself projects, contrary to the *top-down* projects that have science professionals structuring many, if not all phases of the project and typically on larger scales (Eicken et al., 2021). Environmental monitoring benefits greatly from both approaches and a challenge at present is to continuously be aware of how to connect the two: Ensuring representation and influence at the community level while also striving towards the ever-evolving standardization and data quality requirements.

For the research included in this thesis, our citizen science approach in the Danish Mass Experiment 2019 was in many ways expert-steered in terms of the project design, protocols, etc. as we were aiming for high data standards compatible with state-of-the-art scientific data requirements, and because of the inherent educational setting. On the other hand, Astra remained in close contact with participants who, through the inclusiveness of nature types in the sampling protocol, were able to explore nature sites in and around their own immediate schools' environments. Later, when the role of citizen science is discussed as a lever for citizens to impact policymaking, and as a tool to include vulnerable citizen groups, we are highly dependent on the attention to locally based citizen needs and knowledge and inherently working with the concept closer to the *bottom-up* approach.

3.1. The Mass Experiment: Plastics pollution in Denmark

3.1.1. The Mass Experiment by Astra

The Danish Mass Experiment 2019 was the first of its kind – a citizen science project to comprehensively map plastic pollution in various nature compartments, covering a whole nation with assistance from school students. The monitoring project unfolded over three weeks during Fall 2019 and engaged 57,000 students in ultimately collecting 374,082 pieces of plastic litter in local community areas covering the entire Danish Realm (Denmark, Greenland, and the Faroe Islands) (Astra, 2019; Syberg et al., 2020). The National Center for Learning in Science, Technology, and Health in Denmark, Astra, has carried out extensive citizen science projects recurrently since 2007 and has established a dependable participant base throughout the years. For the Mass Experiment projects, Astra works with problem-oriented and explorative science education to create science literacy for primary, secondary, and high school students (Astra, 2023). The theme of the projects changes each year, and so new collaborators are invited from the respective research fields to cooperate on information materials, setup, and execution.

Ultimately, in 2019 Astra reached out to the MarinePlastic consortium and invited the MarinePlastic research team, in which I am employed, to collaborate. The objective was to develop that year's Mass Experiment on plastic pollution in a way that would actively expose the participants to the research field while simultaneously producing new evidence for scientific literature. For this, we provided scientific expertise in the development of a participant-appropriate monitoring protocol, polymer identification process, testing of results reporting in an online database, statistical analyses, and scientific communication of the project results.

3.1.2. Participants

Through their work and engagement with public and private schools across the country for more than a decade, Astra has created a network ensuring stable participant recruitment. Still, all national schools are invited to sign up online for the annual project to recruit as many participants as possible. In early 2019, the first advertisements for the Mass Experiment 2019 on plastic pollution were launched and the registration opened in April. Any teacher, or group leader, could sign up one or more school classes online, and we found that there was an overwhelming interest. For instance, 92 out of the total 98 municipalities in Denmark were represented. Fortunately, Astra was able to expand the participant capacity from 2,500 school classes to 3,500, accounting for 57,000 students in the age range of 6-19 years (Syberg et al., 2020). Geographically, we found that almost the entire nation was represented in the participant group, however, we did not collect or analyze additional socio-economic relevant data for the participating schools.

3.1.3. Protocol design and data analysis

The Mass Experiment comprised of an obligatory part, the sampling activity, and a voluntary part, laboratory exercises in which the older students (grades five and up) could bring unidentified plastic samples back to their school laboratories and identify polymer types (Christensen & Syberg, 2019). Addressing the challenges mentioned in the scientific literature in terms of data quality (cf. section 2.3.2.), we launched a plethora of measures, including simplifying the sampling protocols, supervising the teachers in guiding their students, and testing the monitoring activities before the actual Mass Experiment to be able to adjust procedures throughout (Kosmala et al., 2016). To ensure that all participants were familiar with the research field, sampling protocol, and reporting systems, the teachers received age-appropriate educational materials (developed in cooperation between Astra and MarinePlastic) and sampling kits several weeks before the actual monitoring activity.

For data quality and the possibility to incorporate and assess the results of the Mass Experiment in a global scientific context, we designed the sampling protocol based on the European Union's (EU) Joint Litter Category List under the European Marine Strategy Framework Directive (MSFD) (Galgani et al., 2013). With the students in mind, we modified the classification list to a reduced number of categories (n=22) while making sure to include the top ten plastic categories proposed in the single-use plastic (SUP) directive (European Commission, 2019) for trend assessment and data comparison. Furthermore, since the school classes were asked to monitor the local environment, we modified the general monitoring protocols (which typically apply to coastal sample sites) to encompass seven different nature types for all geographical locations to be represented (Syberg et al., 2020).

Building on Astra's extensive experience in communicating with and including the young participant group, we collaborated on short teaching videos, and graphical instructions for all steps of the monitoring activity (including transact measuring) as well as the voluntary polymer analysis (Christensen, 2019). For instance, we made recognizing the 22 plastic categories simple by designing a sizable sheet with the categories drawn inside large circles in which the students could physically place their samples. By the end of the activity, the students counted the plastic litter items and took notes at the sampling site before the online registration back at the school. For polymer identification, a graphical flowchart was developed to guide the older students in assessing their samples according to seven polymer types (cf. Figure 6).

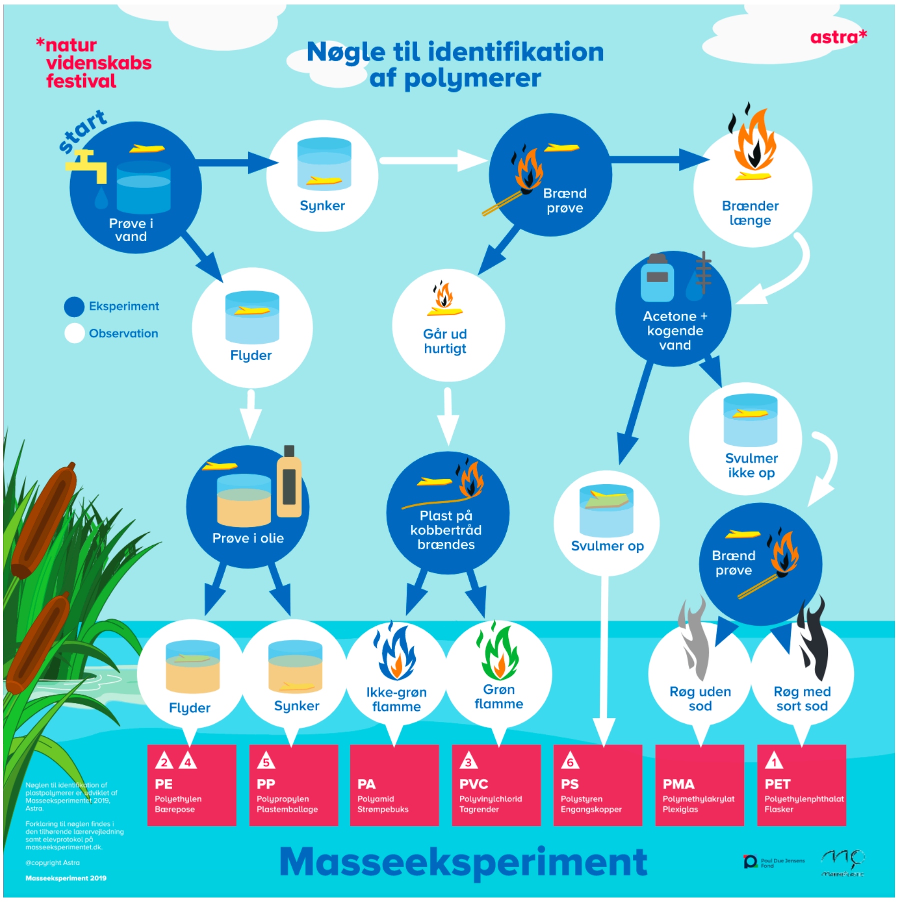


Figure 6: *Classification chart illustrating the steps for polymer identification in the voluntary laboratory categorization part relevant for students in grades five and up. In Danish. From Astra, (2019).*

3.1.4. Results analysis and communication

Thanks to the many engaged teachers and students, we gathered an extensive dataset from 3,542 separate transects. The central tendencies of our data were calculated as median ± median absolute deviation (MAD), according to the Joint Research Center (JRC)'s Marine Litter baseline report (EC & JRC, 2019). Additional calculations of mean ± standard deviation (SD) and trimmed mean (10%) ± standard deviation (SD) gave insights into the distribution around the central values with and without removal of the most extreme outliers. Non-normal distributions of the data caused us to use Kruskal-Wallis rank sum test and pairwise comparisons by Wilcoxon rank sum test when comparing median values (p-value: 0.5). Attending to the validity of the large dataset, we actively contacted participants and schools that have reported the most extreme outliers (in terms of value and GPS coordinates) to verify results and location. Additionally, random samples were conducted at registered locations, and 50 students were contacted at random to confirm their registrations. Lastly, all data was stored with open access at Cern's online repository, Zenodo.

Picture 1: Students testing the monitoring activity in May 2019, with associate professor at RUC, Kristian Syberg. Copyright Astra, photo: Camilla Hey.

As described in section 2.1.1. communication with participants throughout the duration of the project is vital for motivation and engagement (Tredick et al., 2017; West & Pateman, 2016). For this reason, the results dissemination of the Mass Experiment was twofold: A thorough and illustrative results report at eye level was produced for the participating students and teachers to see the fruit of their monitoring activities; and for the academic purpose, a research article - paper (I), Syberg *et al*, (2020) - was published in Nature Scientific Reports. Extensive public media attention was drawn to the project, including TV stories, newspaper articles, radio interviews, and discussions (Syberg et al., 2020). Astra typically evaluates the Mass Experiments in cooperation with external consultants, however this particular year, no systematic evaluation of the project was carried out. However, one question from the online report registration allowed the participants to leave a comment about the Mass Experiment experience and thus provided general feedback on the project.

3.2. Environmental behavior and perceptions in the Mass Experiment

3.2.1. Building on the Mass Experiment

Prior to the Mass Experiment 2019, attention had been drawn to the social effects of citizen science activities (cf. section 2.2.1.), but only a few studies had attempted to measure behavioral changes as a result of participating in interventions focusing on plastic and marine litter. With the aim of studying behavioral changes related to an educational activity concerning marine litter, Hartley *et al.* (2018), designed a survey targeting almost the same target participant group (students, aged 8-18 years) as the one in the Mass Experiment 2019. Inspired by this work, we approached environmental psychology professor Sabine Pahl (Environmental Psychology Group at the University of Vienna) for expert cooperation in developing and analyzing the social implications of the Mass Experiment 2019. During a one-week stay at the University of Plymouth, where Prof. Pahl was affiliated at the time (early 2019), I acquired methodological and theoretical insights for how to design an appropriate survey to answer the main research objective: To test the feasibility of evaluating a large-scale citizen science initiative and gather first insights into the outcomes of this type of program. In the study, we further hypnotized that the intervention would cause an increase in key behavioral concepts of the participants including *risk perception*, *self-efficacy*, *empowerment*, and *self-reported actions* (cf. section 2.2.1.). The collaboration with Prof. Pahl continued throughout the entire study.

3.2.2. Participants

As collaborators on the Mass Experiment 2019 we had, through Astra, unique access to the extensive pool of students (approx. 1% of the Danish population) associated with the project. Since this study recruited participants solely from the Mass Experiment cohort the specific characteristics of the group are identical to the information in section 3.2.1, apart from the age range which, for this survey study, is narrower; from 7-16 years of age. To recruit as many respondents for the voluntary survey as possible, we sent out a registration invitation via email to all team coordinators who signed up for the Mass Experiment 2019. Since participation in this parallel study was voluntary, we aimed for short and precise communication, so that teachers and students would not feel overwhelmed. To the teachers and group leaders who showed interest, we sent a short teacher guide and a link to the online survey. The survey was distributed over two rounds to compare the data; the first round was immediately prior to the execution of the Mass Experiment, and the second round was one week after.

3.2.3. Survey design and development

In compliance with the EU General Data Protection Regulation (GDPR), the surveys were conducted anonymously, and for this reason, there were no requirements for parental consent. However, we were able to have the students report a unique team-id, which each sampling group (typically a school class) was given to link their findings with. This allowed us to compare the survey responses on a team basis, for which we found 48 matching teams in our two data sets consisting of 930 and 830 individual responses (for the pre- and post-survey, respectively).

The study had a repeated measures design, with two almost identical surveys that allowed us to compare the results over time, according to the target variables described in section 3.2.1.; *risk perception* (Catarino et al., 2021; Felipe-Rodriguez et al., 2023; Liobikiene & Juknys, 2016), *self-efficacy* (Bandura et al., 1999; Tabernero & Hernández, 2011), *empowerment* (Hamilton et al., 2022; Turreira-García et al., 2018), and *self-reported actions* (Somerwill & Wehn, 2022). In the development of the survey, we included additional psychological concepts such as *nature-connectedness* (Cheng & Monroe, 2012) and *self-identity* (Carfora et al., 2017), which we, however, did not pursue in the analyses because of scope and time limitations. The only deviation between the two surveys was three additional questions in the survey post-intervention, that evaluated the practical activities.

We were very attentive to the tendency of children (and especially in a school setting) to answer with a *satisficing strategy* (i.e. what they thought we would like to hear or what would be the "correct" answer) (Krosnick, 1991). We restricted the number of questions to a minimum to not overwhelm the respondents, particularly the youngest in the group. We made sure to: Ensure neutrality; formulate questions that were easily understood by all ages; and avoid potentially leading questions, following the literature on the subject (Bell, 2007; Phillips et al., 2014). Furthermore, in the survey introduction, it was emphasized that the questions were not a test and there were no wrong answers.

The surveys consisted of 15 and 18 questions respectively, all with a five-point ordinal scale of text options, except one that had pictures next to the answers and one that offered more than one response (cf. the question on self-reported behavior in Figure 7, to the right). We offered an *"I am unsure.."* option (in Danish: *"Jeg er usikker.."*) to create a neutral response for the participants, knowing that providing this kind of option could lead to an increased probability of choosing that exact one (Bell, 2007), cf. Figure 7.

Every student had internet access and a digital resource (tablet, computer, or smartphone) from which they could access the survey link and complete the survey under teacher supervision. We had the opportunity to test the first version of the survey with students in May 2019 (when the teaching materials, monitoring kits, protocols, etc. for the Mass Experiment were also tried out) and received immediate feedback in person. This only led to minor adjustments.

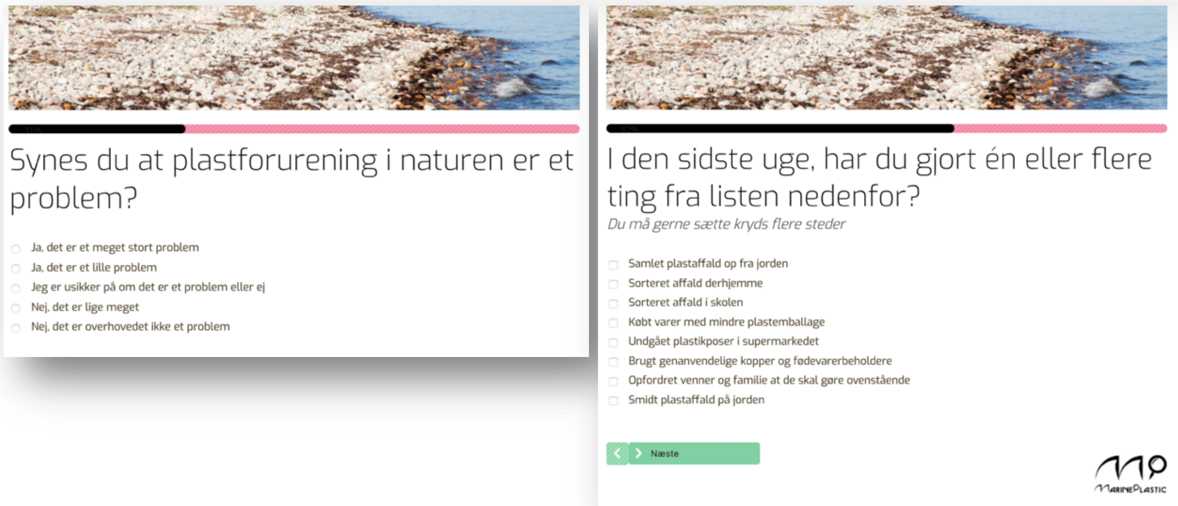


Figure 7: Example of two types of questions asked in the surveys. To the left on risk perception: "Do you think plastic in nature is a problem?" with the responses on a 5-point scale from 1) "Yes, it is a very big problem" to 5) "No, it is not a problem at all". To the right on self-reported behaviors: "In the previous week, have you..?" with a range of options describing concrete actions, where the participant could choose multiple options.

3.2.4. Results analysis and communication

Prior to data examination, we preregistered the study at the online Open Science Framework (OSF) to enhance transparency and structure in our research while also minimizing false positive findings (Forstmeier et al., 2017). We explored our matching data sets, running a Generalized Linear Mixed (GLM) Analysis of variance (ANOVA) on each variable to study potential changes between pre- and post-responses. All values were presented as means ± standard deviations (SD) as the number of participants in the same team could differ from the first time point (before the Mass Experiment) to the second (after the Mass Experiment). We chose to follow up on the main effects with posthoc testing, for which we included a division into two age categories (7-12, and 13-16 years of age) and level of participation (based on the post-survey evaluation questions concerning if and how many activities the student had participated in).

3.3. Citizen science in policymaking

Recalling Figure 1 and plastic's path through modern society, paper (V) operates in the very top sphere, where the management of plastics takes place. During the summer of 2022, I spent three months with our close collaborator in the MarinePlastic consortium, associate professor Steffen Foss Hansen, at the Danish Technical University (DTU) Sustain. The research group there particularly specializes in the policy and regulation aspect of plastics, which was the optimal environment for me to: plan; coordinate with collaborators; carry out the research; and ultimately write the manuscript; for paper (V). This study first sets out to examine the structures for citizen participation in plastic policymaking in the EU. Then it seeks to explore the potential for employing citizen science methods in the pursuit of increased representation of the public in the development and implementation of an effective UN plastics treaty. In this regard, this section will start with a short presentation of how paper (IV) came to be, as the stakeholder analysis performed in paper (IV) offers an initial insight into the citizen stakeholder's limited access to policy impact and thus stands as a stepping-stone to my last study, paper (V).

3.3.1. Stakeholder analysis: Restriction proposal on microplastics

In 2019, members of our research group in MarinePlastic from DTU invited us to collaborate on a stakeholder analysis to understand the status of stakeholder involvement in EU policy. The overarching aim was to map the interests, influence, and importance of prominent stakeholders regarding the European Chemicals Agency's (ECHA) recent Annex XV restriction proposal process on intentionally added microplastics and provide recommendations for decision-makers for increased inclusiveness of all stakeholder perspectives (Clausen et al., 2020). For this, we scrutinized published articles in specialized niche media within the field of microplastic regulation; Chemical Watch, Ends, EURACTIVE, and EUobserver for the period between 2013 and 2019 to identify stakeholders speaking out on the restriction proposal. Further stakeholder identification was carried out by going through all stakeholder comments related to the public consultation on the proposal that had been open from January to September 2019. All stakeholders were sorted into eight overall stakeholder groups and then categorized according to Lienart (2019) as *primary*, *secondary* and *tertiary* stakeholders. We examined stakeholder interests by analyzing and organizing the comments from the niche media sources, along with the public consultation, in five categories: *Criteria*, *principles*, *scientific argumentation*, *research needs* and *other*. Finally, for the stakeholder mapping, each of the stakeholders in the eight categories was analyzed using three related, qualitative methods; 1) on a scale from low to high (Hansen & Baun, 2015), 2) on a *psychometric scale* as done by Olander & Landin (2005), and 3) a *qualitative ranking* of the stakeholders compared to each other. This all resulted in a comprehensive overview of the stakeholder landscape, and of particular interest for this thesis – it revealed the missing and "silent" stakeholders i.e. those we did not find in any of the analyses and neither of the stakeholder channels available by the niche media or the EU regarding the specific restriction proposal. In 2020 the study, which is this thesis' paper IV, was published in PLOS ONE (Clausen et al., 2020).

3.3.2. Recommendations for the UN plastic treaty

Pursuing effective ways to encourage stakeholder participation that not only reflects the EU's intentions of giving equal status to all stakeholders, but also provide inputs employable for policy, we aimed at making a comprehensive research article that encompassed just that. The aim was to conduct this study in time to publish and make our recommendations available to UNEA for the development and implementation of the UN plastic treaty (cf. section 2.3.2.), and specifically the second Intergovernmental Negotiation Committee (INC2) on 29 May – 2 June in Paris 2023. To create a solid foundation for our recommendations we designed our research to; on the one hand, encompass thorough analyses of participation channels in the EU to obtain applied knowledge from the different initiatives in action; and on the other hand, research on how to employ citizen science for policy purposes and providing hands-on suggestions for achieving public representation, policy legitimacy and scientific insights to plastic pollution. Figure 8 illustrates the rationale of paper (V).

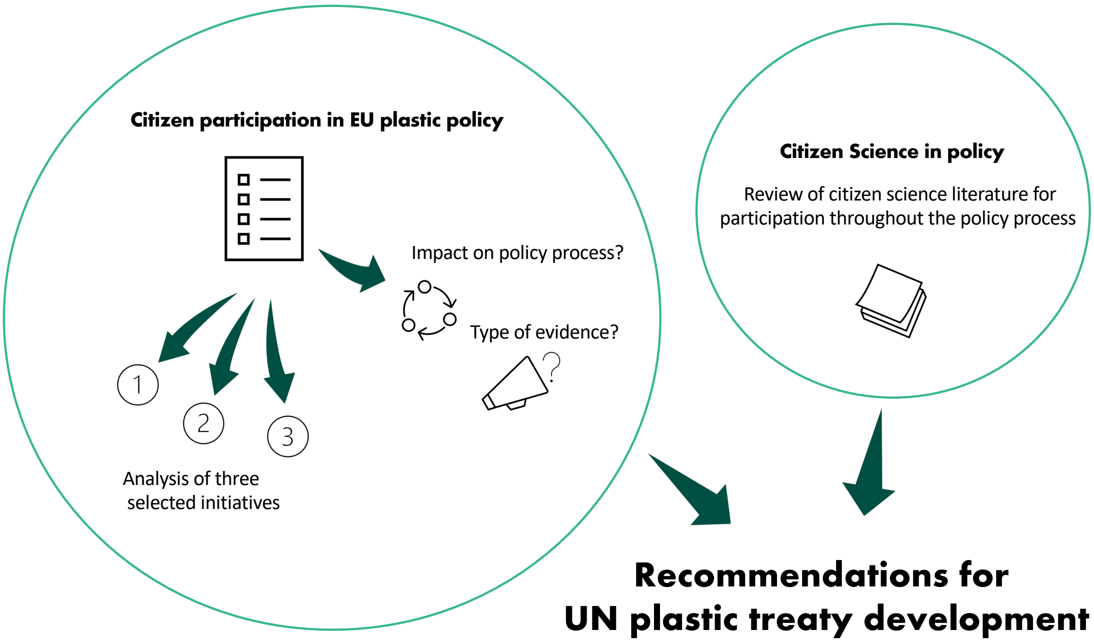


Figure 8: Outline of paper (V) methods. The circle to the left depicts the first section of the study; the identification of citizen engagement initiatives regarding plastic policy initiated by the EU and the analyses of what type of evidence these initiatives provided as well as the assessed policy impact. The circle to the right illustrates the discussion of available literature on CS and policy, that together with the first analyses, amounted to recommendations for the UN treaty on plastic pollution. Own work.

3.3.3. Identifying and mapping citizen engagement initiatives in the EU

First, paper (V) set out to explore the citizen stakeholder group's access to participation in plastic pollution policymaking, and so we initiated our research by identifying current citizen engagement initiatives (CEI) initiated by the EU. We performed a non-exhaustive examination of participatory activities from three sources: 1) The Horizon Europe 2021 – 2027: Ocean Mission (European Commission, n.d.), 2) the JRC's The Citizen Engagement Navigator projects inventory (JRC, 2022), and 3) the general EU website under Participate, interact and vote in the European Union (EU, 2022b). The inclusion criteria were defined to encompass projects and activities that were currently running (as of July 2022), relevant to plastic pollution, and that directly involved citizens (Figure 9).

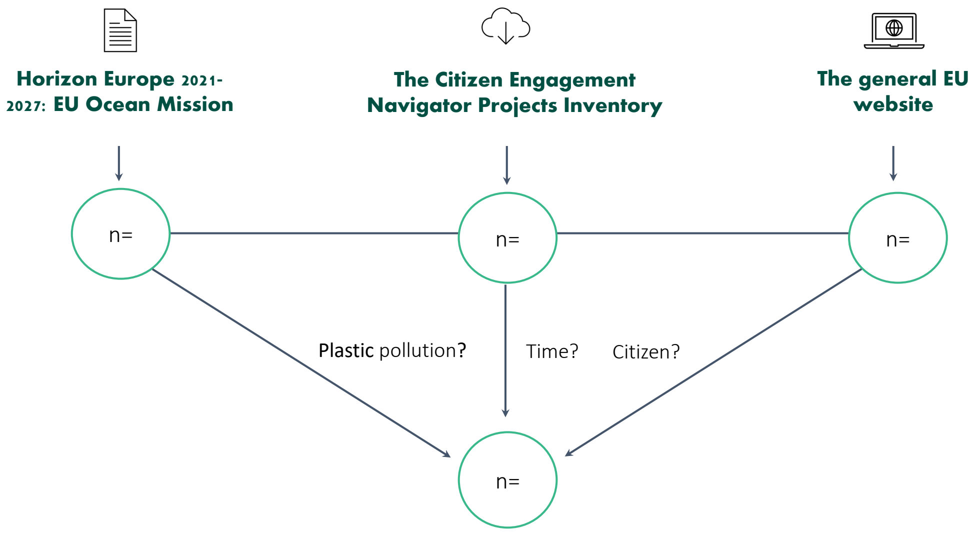


Figure 9: Selection process of citizen engagement initiatives. The first screening identified possible citizen engagement initiatives. The second step presents the selection of initiatives based on relevance for plastic pollution, timeframe, and involvement. From Oturai et al (Accepted).

Next, we were interested in how the identified CEIs impacted the policymaking process in the EU. We analyzed each of the initiatives' policy interference based on the available descriptions and intended aims and mapped them accordingly on a five-stage policy cycle modified from Turbé *et al* (2019) (cf. Figure 10), also used in a similar version by the European Commission(EC) (EC, 2020). Since impacting several, or all, phases in policymaking is beneficial and desirable (Schade et al., 2017), this figure provided us with a tool to assess how the current CEIs influence policy.

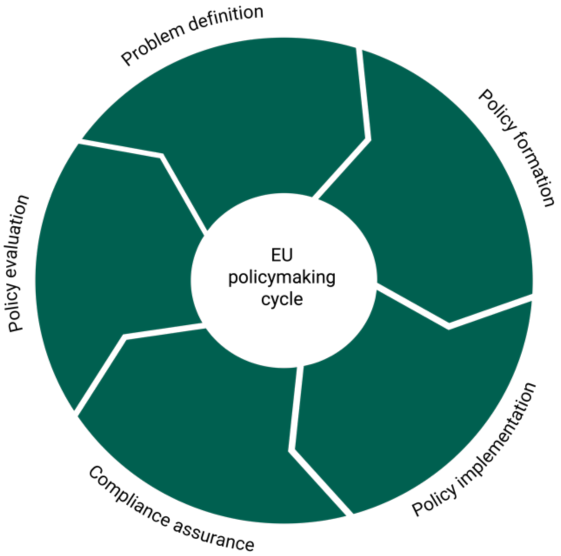


***Figure 10**: Policy process cycle illustrating five stages in EU policymaking. Modified from Turbé et al (2019).*

Additionally, we were curious to understand the type of input for policy the initiatives represented. The EC's toolbox for better regulation Tool #4. Evidence-informed Policymaking suggests three types of data that are equal as evidence for policy input: 1) *Quantitative data* (defines), 2) *qualitative data* (describes), and 3) *opinions* (offers personal views) (European Commission, 2021b). Correspondingly, we examined the input type for each initiative based on inputs that they already at the time had provided or were designed to contribute with.

3.3.4. Analysis of who has a say: Three types of initiatives representing the three input types

Inspired by the findings in paper (IV) where the public consultations in the EU, which are envisioned to include and engage all stakeholders, were leaving out a certain few (Clausen et al., 2020), we were intent on knowing who actually gets to have a say. For this analysis, we included three initiatives from our list of identified CEIs representing three different types of participation, namely: 1) the EC's public consultations Have Your Say; 2) a citizen science project funded by the EU, Plastic Pirates; and lastly, 3) the EU platform for citizen petitions, European Citizens' Initiative (ECI). In each case, we determined the identity of the participants (as they were registered) and evaluated the outcomes in depth according to the Better Regulation evidence types.

The Have Your Say portal is one of the EC's main pillars of stakeholder involvement (European Commission, 2021a). Here, stakeholders are invited to give feedback on proposals, draft regulations or provide scientific evidence input, and thus the information available is extensive making this analysis the most comprehensive og the three. We searched the database of current and previous consultations using the search terms "plastic" and "plastics" and included proposals that were accessible to us yet closed for feedback. All comments for the selected proposals that were submitted by an *EU citizen* were then scrutinized and categorized by nationality along with a summary of the main point to create an overview of the feedback and the necessary profile of the citizens participating in this initiative.

Following, we attended to the available data on the EU funded citizen science project Plastic Pirates monitoring riverine plastic litter to assess who the participants typically are and the type of project outcome. The analysis was based on information from the official project website, and the associated website under EU auspices, along with published literature that had been using the project outcomes as empirical data (searching databases; Web of Science, Scopus, and Google Scholar). Furthermore, we contacted one of the project leaders, Tim Kiessling (affiliated with Kiel University), for clarification of certain aspects.

Lastly, the EU-facilitated online petition platform, The European Citizens' Initiative, represents another type of channel for public participation. To raise a concern or a topic the citizen must meet certain criteria including; forming a group of co-registrants that represent at least seven different EU countries; provide full disclosure of funding and support, along with detailed information on the subject (EU, 2022a). The registrants of an initiative have 12 months to gather one million EU citizen signatures from a minimum of seven different EU countries. In this case, the initiative is qualified to be presented to the EC and the European Parliament (EP) (EU, 2022a). To capture eligible petitions for our research, we used the search terms "plastic" and "plastics", and we included all initiatives accessible to us and that was directly relevant to plastic in the description aim. The analysis was based on the descriptions and the status of collected signatures.

3.3.5. Results communication

The above hands-on knowledge of applied channels to include citizens in EU plastic policymaking created a foundation for us to explore the potential for citizen science as a tool to increase the engagement of the citizen stakeholder group and catalyze policy impact throughout the policy process. While discussing these potentials and limitations, we provide eight distinct recommendations for how the United Nations Environment Assembly could utilize the citizen science methodology to overcome potential misrepresentation when involving citizens and thereby strengthen the ongoing development and implementation of the UN plastic treaty.

At the time of print, the manuscript of paper (V) is accepted with minor revisions at the journal One Earth.

CHAPTER 4. DISCUSSION OF RESULTS AND IMPLICATIONS

Citizen science has been the lens through which I have examined plastic pollution and explored the methodology's ability to achieve its threefold potential while keeping tabs on the existing challenges - and those that potentially could surface. This chapter will bring forth the main findings of the thesis and in the light of current literature, I will discuss the implications for working towards sustained scientific outcomes; social effects; and policy relevance as well as uptake when working with citizen science. The structure of the following sections will adhere to the three research questions presented in section 1.3., and thus begin with understanding how the citizen science methods may supplement traditional monitoring based on the experiences from the Mass Experiment in paper (I). Afterwards, the findings from papers (II) and (III) will offer insights into the complexity of studying how citizen science programs may support changing human behaviors and perceptions regarding plastic pollution. Finally, I seek to distinguish the place for citizen science in policymaking with offset in the results from papers (IV) and (V), contributing to the growing scientific debate on how the coming UN plastic treaty can be effective.

4.1. Scientific outcomes of the Mass Experiment

4.1.1. The Mass Experiment as a scientific mapping of plastic litter in Denmark

When the results from the Mass Experiment 2019 were published in early 2020 it came as the first mapping of plastic litter covering an entire nation. From the Mass Experiment, we find that the thousands of student citizen scientists were successfully employing scientific protocols aligning with state-of-the-art guidance documents, and were able to produce results that were comparable with data produced by professional scientists. Among many key findings, the collected data created a full picture of the omnipresent nature of plastic waste seeing that only 2 % of all the 3542 sample sites registered no plastics. Also the importance of embracing a diverse and comprehensive spatial distribution beyond the typically studied marine and coastal compartments were highlighted, see Figure 11 (Wang et al., 2020).

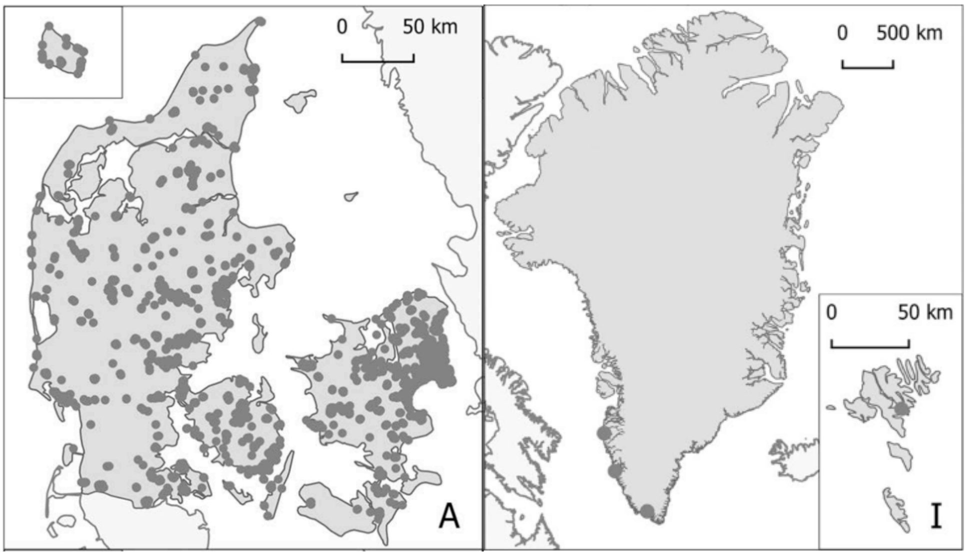


Figure 11: A map of Denmark, the Faroe Islands, and Greenland. The dark grey dots indicate the separate 3,548 samplings by students during the Mass Experiment 2019. 92 out of 98 Danish municipalities were represented. From Syberg et al., (2020).

The monitoring activity proved to be capable of evaluating on current legislation. For instance, very few plastic bottles were found (ranking 15th and 21st out of the 22 categories, cf. Table 2) compared to other surveys of marine litter where this category is among the top ten most commonly found categories, which may in large parts be owed to the comprehensive and well-implemented Danish bottle deposit system (EU, 2013). Likewise, the extensive dataset pointed to areas that require, or are already of, political interest. The high amounts of single-use plastic (SUP) waste, such as packaging from candy and crisps (ranked 3rd of the 22 categories) and cigarette butts (ranked 1st) emphasized the need for action on these types of plastic products (cf. Tabel 2).

Table 2: Overview of the plastic items collected in the Mass Experiment 2019. The total amount of items collected under each of the 22 categories is shown as well as the percentage contribution of the total of each plastic item. The plastic categories are numbered 1–22 for this study. From Syberg et al., (2020).

Category	Plastic items	% of total	Category	Plastic items	% of total
1. Shopping bags	9264	2.5	12. Straws and stirrers	6304	1.7
2. Small plastic bags	28,011	7.5	13. String and cord	6740	1.8
3. Drink bottles (≤ 0.5 l)	4550	1.2	14. Nets and pieces of net < 50 cm	1913	0.5
4. Drink bottles (> 0.5 l)	1260	0.3	15. Nets and pieces of net > 50 cm	694	0.2
5. Food containers incl. fast food Containers	6428	1.7	16. Plastic pieces 2.5 cm > < 50 cm	67,387	18.0
6. Plastic caps/lids; drinks	8545	2.3	17. Polystyrene pieces 2.5 cm > < 50 cm	17,316	4.6
7. Plastic caps/lids; unidentified	6338	1.7	18. Cotton bud sticks	1264	0.3
8. Cigarette butts and filters	112,018	29.9	19. Sanitary towels/panty liners/backing Strips	2745	0.7
9. Crisp packets/sweet wrappers	48,299	12.9	20. Other plastic/polystyrene items (identifiable)	24,800	6.6
10. Cups and cup lids	7539	2.0	21. Balloons and balloon strings and sticks	2397	0.6
11. Cutlery and trays	3631	1.0	22. Other rubber pieces	6669	1.8

This corresponds with the prioritization of the European Union (EU) to implement the SUP Directive of 2019, which targets the top ten most commonly found single-use plastic items via a mix of bans and other measures, including extended producer responsibility. In a similar manner, Kiessling *et al.*, (2023) recently systematically evaluated the effectiveness of the SUP Directive based on large-scale data from three citizen science projects, the Plastic Pirates (Kiessling et al., 2019, 2021), the International Coastal Cleanup (ICC) (Ocean Conservatory, 2023) and Marine LitterWatch (EEA, 2023), along with data from the Oslo-Paris agreement (OSPAR) protocol (OSPAR, 2010). A significant remark should be made regarding the fact that these most prevalent plastic litter categories are all tightly connected to human activities and point to adverse littering behaviors (Astra, 2019; Syberg et al., 2020). All results from this study were directly comparable to monitoring activities carried out by science professionals or governing agencies owing to the careful alignment of methods to harmonize with the guidelines of the Marine Strategy Framework Directive (MSFD) and OSPAR, as well as Astra's years of experience with running comprehensive citizen science projects and close collaborations with the enormous participant group.

4.1.2. Complementary to traditional monitoring programs?

Monitoring is a required first step to understanding the abundance and distribution of plastic pollution in the environment (Nelms et al., 2022; Subramanian, 2022). Currently, there are monitoring programs in full effect carried out by national and international organizations and governing bodies (cf. section 2.1.1.), which incites the question of what else citizen science can offer environmental monitoring. Assumptions may arise for whether citizen science projects altogether simply are cheaper versions of large-scale traditional monitoring programs, that even risk compromising scientific accuracy and data quality (Bonney et al., 2014). As literature previously has established (reviewed in paper (V)) data quality assurance measures are plentiful and already at hand (Bird et al., 2014; Fraisl et al., 2022), this section will rather focus on the scientific contributions to monitoring plastic in the environment sidelined with traditional practices by researchers. The argument is thus not concerned with how monitoring via citizen science should replace or can compete with traditional monitoring, but with how they may supplement one another. For this purpose, the Mass Experiment 2019 will represent citizen science projects, while the Danish Center for Environment and Energy (DCE) exemplifies the national monitoring activities.

In the Mass Experiment, we saw that only through the great support and attendance of the participating students, could we present such a spatially diverse and comprehensive representation of the state of plastic pollution in Denmark (Syberg et al., 2020). This type of data is not accessible to the DCE, that are limited to selected reference sites (Dickinson et al., 2012; Feld et al., 2020). However, conducting a standing-stock monitoring project will always only create a snapshot of plastic litter abundance and types at that exact moment in time. This data is useful for many purposes but lacks the detailed knowledge of trends (seasonal, societal, and similar impacting factors) that repeated and accumulative surveys of the same study sites can provide (EU, 2013). Recalling the protocol design for the Mass Experiment 2019, the sampling classification was modified to fit the participant group, by reducing the number of plastic litter categories to 22 (cf. section 3.1.2.). For the national surveys by the DCE, the categorization considers more than 100 different types of plastic waste, which enables a considerably more nuanced picture of the litter composition (Strand & Metcalfe, 2016). Because of hard-to-access sample sites (e.g. water column) and practices that require technical instruments or scientific expertise (e.g. biota or atmospheric sampling), for the most part citizen science monitoring activities are situated on sandy beaches with macroplastics as sampling targets (GESAMP, 2019; Kawabe et al., 2022).

There are distinctive attributes to both types of monitoring approaches, and what the traditional surveys, as by the DCE, can deliver in terms of analytical detail and trend insights, the Mass Experiment seems to complement by e.g. highlighting the greater picture of different nature types with sufficient data compliance. In addition, the Mass Experiment 2019 had an outreach to the public that plays an important part in the plastic pollution context through vast media attention and practical collaboration with the thousands of participants with impacts that will be focused on in the following section.

4.2. Social implications of the Mass Experiment

4.2.1. No effects, but with the preconditions in place

One of the prominent findings in the results report from the Mass Experiment 2019 was that the majority of the plastic litter found was discarded plastic products for single-use purposes derived from human consumption, including cigarette butts, snacks packaging, and bags, cf. Table 2 (Astra, 2019; Syberg et al., 2020). The interlink between behaviors and plastic pollution became evident at that and underlined the relevance of our study paper (II) on how the Mass Experiment project might promote a change in, among other things, perceptions and behavior.

With only a few behavioral surveys regarding citizen science interventions published before 2019, we carried out the pre/post surveys in parallel with the monitoring activities, hypothesizing that we would see a positive change in our datasets. Nevertheless, we found no significant changes for any of the measured variables, including the three in focus; *risk perception*, *self-efficacy*, and *empowerment* (cf. section 3. 2.3.). Quite interestingly there was a noticeably high baseline for almost all variables attesting to preexisting concerns, knowledge, etc. among the students, cf. Figure 12, leaving very little room for improvement, known as a *ceiling effect* (Liefländer & Bogner, 2018; Oturai, et al., 2021). As a possible explanation for this, we propose the general environmental concern in Denmark, which is ranking high in comparison to other EU countries (EFSA, 2019; Ipsos, 2019). The same high concern among school students is reflected in literature from around the globe, e.g. the United Arab Emirates (Hammami et al., 2017), Hong Kong (So et al., 2016), and, where our study has its roots, in the UK (Hartley et al., 2015b). A supplementary remark regarding the high concern levels of the general public can be made concerning our review of current literature on citizen science methods for monitoring human health effects of plastic pollution, paper (III). Studies show that particularly human health effects of plastics are triggering concern, which invites for application and expansion of citizen science methods in the field (Bertsou & Caramani, 2022; Davison et al., 2021). The methods are readily available to include citizens in the healthcare sector, however we found them to remain unexplored at the time being. With few modifications to existing protocols, as we demonstrate in a current review (paper (III)), citizen science methods could potentially be used to effectively monitor human health effects of plastics (Oturai et al., 2021).

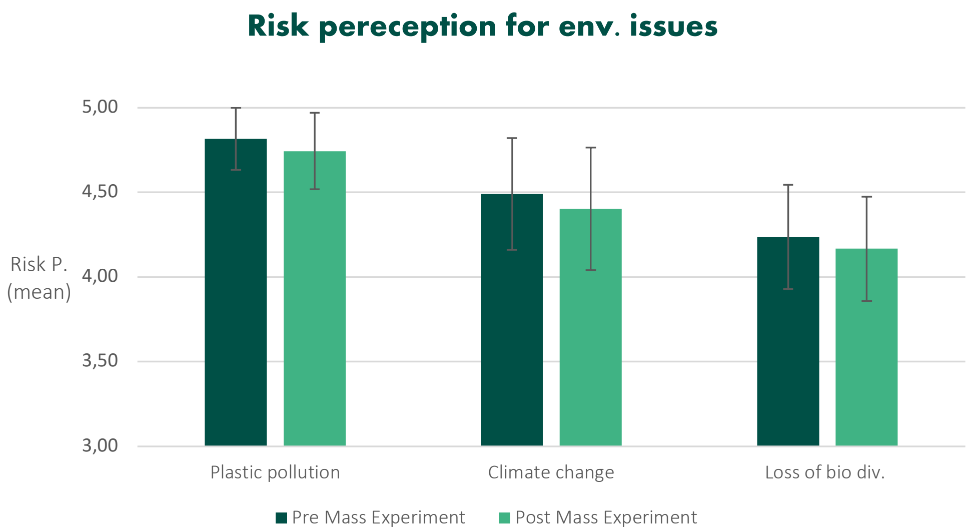


Figure 12. *Bar chart with standard deviations on the perceived risk of three environmental issues: Plastic pollution, climate change, and loss of biodiversity. We find that results for pre- and post-responses, for each of the three variables are high (above four on a five-point scale), particularly, but with no significance for change over time. From Oturai et al., (2021).*

As stated, a first glance our results indicate no significant effects of participating in a citizen science activity. A further look, however, goes on to show that the participants were already highly aware, concerned and did perform PEBs for plastic pollution, causing an optimistic outlook for reinforcing the behaviors of the participant group, and positively affecting their social surroundings (cf. section 2.2.2.). Mirroring the scarce literature on the role of age regarding children's environmental behaviors, we found indicators for specific behaviors when dividing the participant group into two age groups; a younger (7-12 years of age) and an older (13-16 years of age) (J. D. Miller, 1975; Oturai et al., 2021). Particularly, the youngest group deviated from the overall findings concerning specific reported behaviors such as *picking up litter* and *encouraging others to do PEBs*, where we found drops for both after the Mass Experiment (Oturai, et al., 2021). In the article, we discuss whether *experience-discrepancy* or disappointment with the level of experienced pollution in nature could explain these findings.

Addressing the role of age, the literature suggests that the youngest age group increasingly needs support in comprehending the sometimes complex issues in focus, while interventions aiming at changing behaviors in young adolescents are found to benefit from respecting the participants' autonomy and capability to decide elements of the activities to have an effect (Yeager et al., 2018). The Mass Experiment 2019 did offer some variation in activities for the participants according to age (cf. section 3.1.3.) which however could be further highlighted for future interventions. Returning to the research objective regarding how to appropriately measure and encourage behavior change in citizen science projects, the importance seems to lie in the design of the interventions, just as it applies to ensuring data quality, which I will try to unfold in the following.

4.2.2. Is it all in the design?

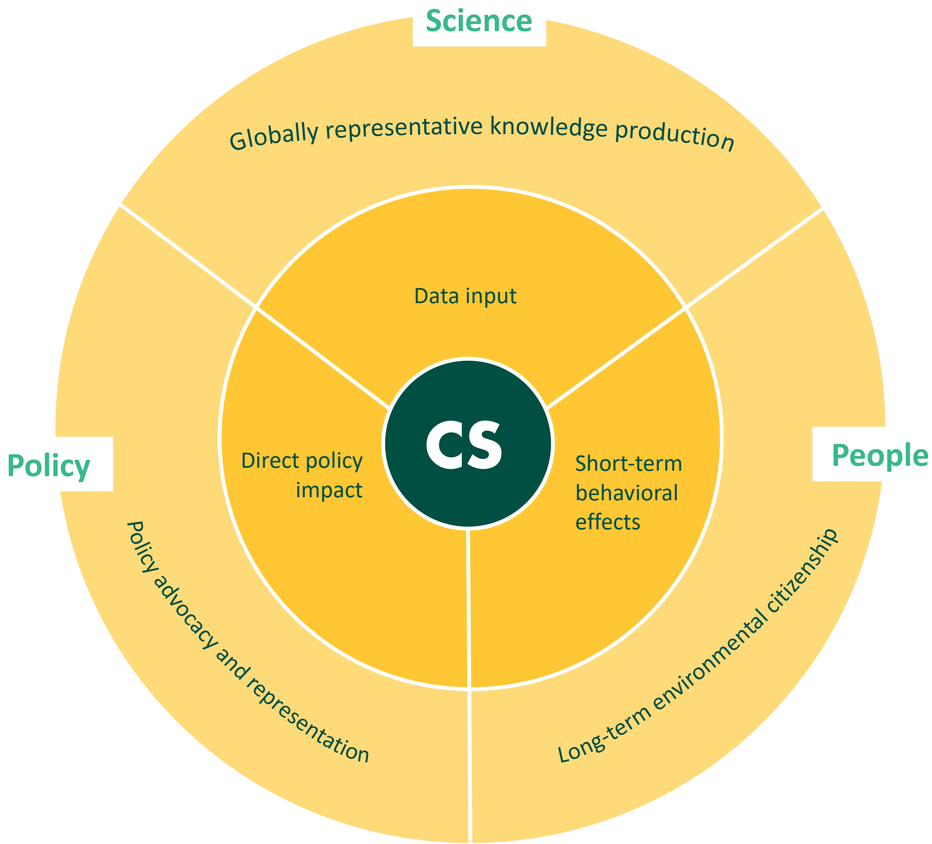
Today, just a few years from 2019 when we designed the surveys for paper (II), already several studies have been published with deeper insights regarding the evaluation of social processes, including risk perception as well as state-of-the-art methods to measure knowledge and behavioral impacts of citizen science programs (Jørgensen & Jørgensen, 2021; Somerwill & Wehn, 2022; Yoon et al., 2021). In this context, careful considerations of the characteristics of the participant group in general is pertinent when designing a citizen science project. Studies on the most basic sociodemographic information, such as *gender*, *age*, *education*, *geographic location*, and *income* already suggest target groups of interest for environmental citizen science activities. For example, Soares *et al* (2021) point to individuals of the male gender along with youth in general, to be of interest as target audiences for intensified interventions aimed at increased scientific knowledge about environmental problems and pro-environmental behaviors (PEB) regarding plastic pollution. In a hypothetical recreation of the Mass Experiment 2019 and the associated behavior study, we could benefit from holding increased attention to the factors such as *age*, preexisting *knowledge* and *concern*, socioeconomic demographics, etc. to enable a clearer picture of which social effects would be attributed to the citizen science activities.

An important aspect to note is while the integration of environmental psychology into the citizen science praxis is inherently necessary to understand the behavioral impacts, this is an immense resource-demanding maneuver, and only very few published citizen science programs evaluate participant impacts (Severin et al., 2023). As mentioned, recommendations and guides to the interdisciplinary requirements are emerging in these years to effectively measure citizen science project outcomes (Somerwill & Wehn, 2022), which likely will enable more citizen science practitioners to consider the social aspects of their project designs. However, ensuring high-quality standards that can supplement monitoring done by science professionals, while also considering project designs that provide the suiting conditions to encourage behavioral changes inherently increase the complexity and workload of the project practitioners. Recalling The Ten Principles of Citizen Science developed and described by the European Citizen Science Association (ECSA) vaguely includes "social benefits" and "learning opportunities" as requirements in one of the principles (Robinson et al., 2018), and may need to be more specifically addressed to receive a broader application for citizen science practitioners and projects.

4.2.3. Short-term and long-term influence

Reflecting on whether citizen science can constitute a more direct path for public participation in plastic pollution policy, this thesis regards the interdisciplinary approach of scientific, policy, and behavioral implications of citizen science projects. In this context, an observation should be made as to how measuring effects in one discipline may not necessarily be comparable to the approaches in the next. The scientific outcomes of citizen science projects are inherently straightforward to measure as section 4.1.1. and 4.1.2. exemplifies, and is by far the most commonly published (Jørgensen & Jørgensen, 2021; van Noordwijk et al., 2021). In the same manner, the direct impact on policy processes, which will be discussed in the following section, is also readily assessable in praxis. Meanwhile, environmental behaviors, perceptions, and awareness are in nature complex to measure, and particularly sustained effects in general of citizen science projects remain understudied (van der Linden, 2015).

The current state-of-the-art approaches to impact assessments of citizen science programs in terms of both scientific outcomes and environmental behaviors appear to be focused solely on the short-term effects and impacts of interventions rather than on long-term and sustained PEBs (Phillips et al., 2014; Schaefer et al., 2021; Somerwill & Wehn, 2022). In line with literature on long-term environmental issues such as climate change and plastic pollution, we realize long-standing behavioral shifts are required (van der Linden, 2015), and thus we suggest that beyond the measured effects of isolated projects, there may lie a potential for deeper impressions and environmental understanding at personal and community levels. These further intangible effects are pointed to frequently in the literature (Robinson et al., 2018; van Noordwijk et al., 2021) yet are rarely described in detail. Further research on whether and how citizen science promotes environmental citizenship and PEBs on a longer timescale would be welcomed, although



these inherently will be progressively difficult to measure, and would require the development of solid guidelines for citizen science practitioners. Figure 13 illustrates the two levels of implications described in this section.

Figure 13: *The direct implications (inner circle in dark orange) and the long-term potential impacts (outer circle in light orange) of citizen science are depicted from an environmental, psychological, and policy perspective respectively. Own work.*

4.3. Citizen science translation into policy

4.3.1. Are all inputs equal for policy?

As an initial step to understanding how citizen science may lift citizen participation in plastic pollution policy, it has been essential to study how citizens are involved in decision-making currently. The stakeholder analysis conducted for paper (IV), regarding a recent restriction proposal on plastics in a European setting, unveiled among other things that the citizen stakeholder group was entirely unrepresented. Similarly, the stakeholder groups that may represent citizen interests (e.g. International Consumer

NGOs and International Environmental NGOs) were deemed to hold low influence (cf. Figure 14) (Clausen et al., 2020).

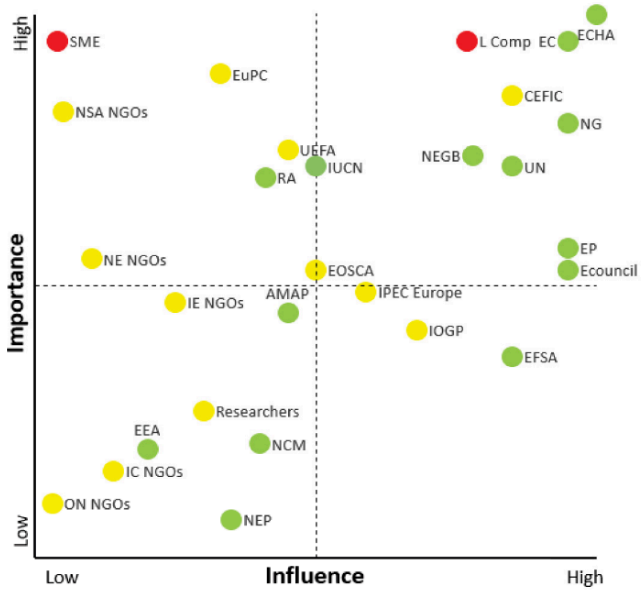


Figure 14*: One of three different importance-influence matrices from paper (IV). In this one, the stakeholders were assessed on a scale from high to low. International Consumer NGOs (IC NGOs) and International Environmental NGOs (IE NGOs) both appear in the lower left quadrant. From Clausen et al.,(2020).*

The analysis was based on a niche media analysis and the comments registered for the open consultation under the auspices of the EU. Our findings are consistent with Hierlemann *et al* (2022) that deem the public consultations Have Your Say, along with other participation instruments employed by the EU, including the European Citizens' Initiative (ECI), inefficient - or misplaced at best - in representing European citizens. Building on this, we designed paper (V) to investigate and analyze several initiatives by the EU that are currently in place to engage citizen participation in policymaking. In line with the insights from paper (IV), we find the analyzed citizen engagement initiatives (CEI) to be a work in progress. Particularly, when it comes to establishing the direct policy implications of each of the ten initiatives, the information available would typically be unclear, while we saw a tendency for the included initiatives to accumulate in the *problem definition* or *policy evaluation* phases when placed on the policy cycle (cf. Figure 15).

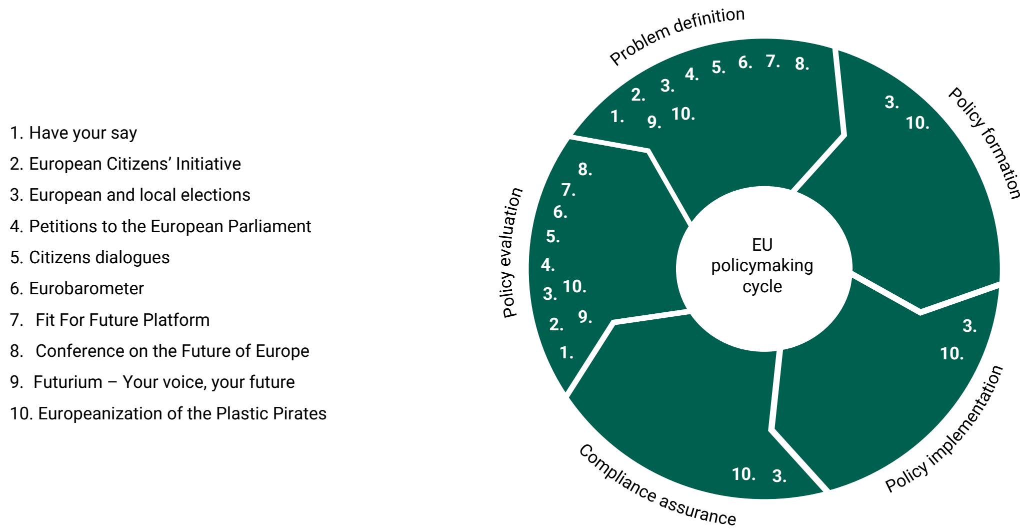


Figure 15. *Sub-results from paper (V). To the left is a list of the ten included citizen engagement initiatives in the EU regarding plastic policy. To the right, the ten initiatives are mapped according to the direct impact on the policy process. From Oturai et al., (Accepted).*

We question whether the European Commission's (EC) Better Regulation campaign's claims of ranking *opinions* alongside *qualitative* and *quantitative evidence*, hold true in practice. There was scarce accessible information for participants concerning most of the initiatives on how the provided comments, dialogue or feedback would be implemented in any policy practice, leading us to suspect that citizen participation that provides opinionated inputs risks ending up as mere inspiration for policy. We found that European elections (no. 3 in Figure 15) had a reoccurring impact on the steps throughout the policy cycle because of the general strong (but rather indirect) influence of political direction. Similarly, when examining the citizen science initiative Plastic Pirates (no. 10 in Figure 15) we found an impact on all five policy stages, whereas the impact had a more tangible aspect. We argue that the influence fundamentally is owed to the type of input for policy, which in the case of Plastic Pirates is *quantitative* in the form of scientific data for policy guidance (Oturai et al., Accepted). Large-scale data from this citizen science project has among other things contributed to a recent evaluation of the Single-Use Plastic (SUP) Directive's potential for reducing plastic pollution at coastlines and riversides (Kiessling et al., 2023). We, along with other researchers, will moreover advocate for policymakers to systematically and transparently report on participation processes and outcomes to increase democratic legitimacy (Bäckstrand, 2006; Hierlemann et al., 2022).

The main argument that I want to stress is that seeing that the current channels for participation are not efficiently giving citizens the voice that they may have been designed to do, it seems obvious to pursue the potential of communicating citizen agendas through science, represented in our study as the citizen science program the Plastic Pirates. A growing number of published studies already highlight how citizen science can be used in a policy context supporting our findings (EC, 2020; Nelms et al., 2022; Turbé et al., 2019). Yet, just as we have established for science quality and social effects, a range of specific elements ought to be considered in the development of citizen science projects to be suitable for policy. These essential aspects will be discussed in the section below and at that address the last of the research objectives concerning the prospects of citizen science to translate to policy and increase policy legitimacy.

4.3.2. How does citizen science translate into policy?

Arriving at the top sphere of this thesis' three-part approach to citizen science (cf. Figure 1), I aim to discuss the indicators of citizen science used in policy identified in our research and literature. There seem to be two advances to policy influences: Scientific data inputs for policy, and then a more elusive movement pushing policy direction. First, and mostly treated in the literature, is the direct use of citizen-generated data as evidence for policy. Several studies, e.g. Schade *et al* (2021) and Turbé *et al* (2019), offer concrete and detailed insights into exactly how citizen science inputs can inform and strengthen policy processes in European environmental policy. This includes the necessity of governmental support and cooperation to clarify evidence needs; scientific quality assurance; and bridging gaps between policy and communities (Turbé et al., 2019). The latter is emphasized in a recent, that is also the first, implementation of citizen science practices for the Sustainable Development Goal (SDG) indicator monitoring at a national level, where the linkages between governmental and local citizen sources monitoring were paramount for creating enabling environments for inclusive data ecosystems (Fraisl et al., 2020; Fritz et al., 2019; Olen, 2022). As mentioned previously, the literature on standardized monitoring practices (EC, 2020; EU, 2013; GESAMP, 2019; OSPAR, 2010), quality assurance methods (Fraisl et al., 2022; Mayer et al., 2022), and data management (Roman et al., 2021; Schade et al., 2017) is substantial and growing rapidly in numbers which by now provides a first step towards increased uptake into policy.

Nevertheless, global harmonization in terms of indicators, reporting criteria, target matrices, data platforms, etc. is still lacking which is hindering worldwide monitoring frameworks that are required for plastic pollution policy action on a global scale (Lusher & Primpke, 2023; Subramanian, 2022). This is indeed one of our central recommendations for the development of the United Nations (UN) plastic treaty presented in our study on citizen science relevance for the development of the upcoming UN treaty, paper (V). We further pinpoint the pivotal role citizen science can play and provide a range of recommendations that align with the above suggestions for amplified policy uptake, and among other things include considerations in terms of consistent funding and equal access for vulnerable communities to ensure a global-spatial distribution of data-collection and inclusion of vital local knowledge (Kawabe et al., 2022; Oturai et al., Accepted).

Secondly, the more intangible translation of citizen science impacts directing policy agendas beyond scientific evidence may be harder to grasp (cf. Figure 13). Van Noordwijk et al (2021) highlight several pathways to environmental change by citizen science, and stress how participants and communities engaged in citizen science activities can inspire public support for environmentally friendly causes and push for policy change, and may even lead to more effective policy change than the scientific evidence alone (Van Brussel & Huyse, 2019). On a similar note, Jørgensen & Jørgensen (2021) argue that citizen science projects can foster environmental citizenship if they throughout the activities uphold particular preconditions such as exposure of the participants to; *collectiveness* towards a common goal, *situatedness* as a lived experience, and *connectedness* between collected data and the larger environmental issues.

Regarding potential policy influence, as we describe in paper (I), in addition to our examination of the scientific contributions as well as particular behavioral effects of the intervention, the Mass Experiment 2019 received extensive media attention and sparked a public debate on plastic waste and policy action at the time (Syberg et al., 2020). Although we do not know for certain, or have the means to study what effect this widespread attention could lead to in terms of general public sentiment, we know that the role of the media can portray environmental issues and steer public risk perceptions that in turn may advocate policy support or criticism (SAPEA, 2019). Without knowing the links, Danish policy initiatives followed in the wake of the Mass Experiment 2019 including a campaign launched in Summer 2020 by the Ministry of Food, Agriculture and Fisheries of Denmark targeting cigarette butt littering (Ministry of Food, Agriculture and Fisheries, 2020.)

While policy adaption of citizen science is yet to take off in full effect in EU policy (Nascimento et al., 2018), very recent advances at understanding and establishing sustaining citizens science frameworks look promising and will be interesting to follow, including the report Mutual Learning Exercise Citizen Science For Policy Practice (2023) by the EC, and best-practice citizen science for policy purposes (EC, 2020; European Commission, 2023; Schade et al., 2017, 2020). Bridging the gap between public authorities and local citizen science schemes stands as a central barrier, and improved policy attention to the capacity of citizen science to assist in unveiling the yet invisible abundance of plastics in the environment should be explored at all governance levels, and for which paper (V) serves its purpose (Subramanian, 2022; Turrini et al., 2018).

4.4. Chasing a moving target

Conclusively, my reflections on working with the threefold potential of citizen science will stand as the concluding remarks of my Ph.D. journey and the past years of working with plastic pollution and citizen science. This section echoes considerations of the role of the citizen science practitioner and what the ever-moving scientific field means for the practice.

Many and most environmental citizen science projects have a single or double objective of producing monitoring data by scientific rigor while enhancing citizen engagement and awareness (Van Brussel & Huyse, 2019). At present, attention is directed at a third and important aim of informing and influencing the policy landscape related to the field of inquiry, to which this thesis' research is also contributing (Turrini et al., 2018). Through the work of this thesis, I wonder whether citizen science can uphold legitimacy at the threefold potential if high excellence is assumed for all three fields, a task that naturally falls in the hands of the citizen science practitioner.

In the democratic institutions that are the UN and the EU, a continuous and increasing flow of activities and measures for including the public emerges. In immediate continuation hereof it seems widely important to evaluate these channels to ensure and confirm the desired impacts (as we aim to do in papers (IV) and (V)). Alignments between the policy processes and participatory programs are necessary so that parallel processes that are not mutually beneficial do not occur. And evaluation must be enforced so that impediments of public participation do not subsist, or risk being repeated. As we discuss, adherence between local citizen organizations and large-scale monitoring programs, as well as collaboration and attention from governance is a prerequisite for ensuring the fine balance of enhancing participation, equitable funding accessibility, data availability and quality, and policy relevance. And thus I want to stress and suggest a considerable portion of the responsibility should be placed on governing institutions, as possessors of power and resources.

The citizen science research field is constantly in motion. Environmental psychology evaluation frameworks (Kaiser, 2020) as well as the development and refinement of scientific methods keep emerging, and so being a citizen science practitioner requires close observance of the ever-evolving fields to stay up-to-date with best-practice methods (Lusher & Primpke, 2023; Schaefer et al., 2021). The work of papers (I), (II), and (III) all accentuates this art of chasing a moving methodological target. Nevertheless, reviews of the literature reveal reoccurring problems for citizen science projects to sustain high levels of scientific data quality combined with deep citizen engagement and policy influence (Van Brussel & Huyse, 2019). In this regard, I wonder if the rigidness of implementation of scientific, social, and policy procedures and measures may hinder the participatory openness and immediate purpose of doing good for nature and wildlife that can allow for citizen motivation and attraction (West et al., 2021). The entry requirements for participation in many available citizen science projects are minimal, i.e. the training and attendance are easily accessible for a broad target audience. For instance, low demands are associated with joining a beach clean-up at random, which I believe to be a strong suit and a central part of the methodology. A challenge of implementing several guidelines may be the bureaucratic tradeoff and hereby a risk of volunteer discouragement as environmental decisions are still largely driven by convenience (Nuojua et al., 2022). Yet, during this thesis research and by examining numerous citizen science projects of varying kinds, it is evident that there do exist examples of programs that successfully undertake the threefold potential. Today, as the scientific literature; guidelines and recommendations; and not least political will, for environmental citizen science, are emerging in rising numbers, I am confident that projects will only improve and expand throughout the field - if citizen scientists and practitioners, through networks and research, remain observant with the moving field.

CHAPTER 5. CONCLUSION

The scientific contributions of this thesis attest to the complexity of plastic pollution as an interdisciplinary research field. Through a multifaceted methodical approach, I aimed to explore the threefold potential of citizen science to support plastic pollution reduction. Based on the analyses and discussions of a comprehensive citizen science project and participatory initiatives in the European Union (EU) and the United Nations (UN), the impacts of citizen science in the scientific, social, and political domains were examined. That work led to the realization and cementation of the distinct capability to incorporate central preconditions for all three fields within citizen science practices.

The five studies included here illustrate the magnitude of citizen science application, and among other things showed the first national mapping of plastic litter based on citizen science data in the Mass Experiment 2019. We found that plastic pollution monitoring could produce scientific data outcomes comparable to traditional monitoring programs, and with additional advantages can serve as a complimentary monitoring practice. We then aimed to explore the methods for measuring particular social effects of the participants in the Mass Experiment 2019 and found that the design of the citizen science projects, and evaluation instruments alike are decisive factors for encouraging pro-environmental behavior (PEB) changes and being able to test them. Lastly, the analyses of current channels for including the public in plastic pollution policy in the EU clearly illustrated challenges with effectively representing EU citizens. Furthermore, the subsequent examination of citizen science outcomes applicability for policymaking and the United Nations (UN) plastic treaty specifically, policy and public gains were proposed under several prerequisites.

As a concluding remark, by working with and in multiple research fields simultaneously, I have realized the inevitability of collaboration across sciences in tackling complex environmental problems such as global plastic pollution, and for that purpose, I believe that citizen science holds a favorable position as a versatile methodology. I envision the future of citizen science research to continue to grow at a rapid pace, and to move in a direction that will enable and develop the threefold potential of the field. I also anticipate that the increasing tasks of the citizen science practitioner will be accentuated and supported in the coming years.

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